HANDBOOK

FOR

MECHANICAL ENGINEERS.

BY

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SECOND EDITION, REVISED AND ENLARGED.

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PREFACE.

The favourable reception which was accorded to the "Notes in Mechanical Engineering," outside the circle of students for whom they were originally compiled, has induced the author to recast the whole under a new title, and to include additional matter, with the object of rendering the work still more acceptable to engineers in practice. Busy men must have facts and opinions put before them as briefly as possible, and therefore no apology is requisite for giving the information in as condensed a form as is compatible with accuracy.

60, Queen Victoria Street,
London, E.C.

1st *October*, 1890.

EXTRACT FROM

PREFACE TO FIRST EDITION.

The present work . . . is not intended in any way to supersede the ordinary text-books, but simply to supplement them in the form of a student's own notes, which should represent a summary of his reading and study. The notes are compiled from various sources; in many cases the authority is given, in others the information is original, or has been derived from sources of which no record has been kept.

60, Queen Victoria Street,
London, E.C.

1st October, 1883.

EXTRACTS FROM

PRESS NOTICES, ETC. OF FIRST EDITION.

"A capital little text-book, giving a good deal of practical, trustworthy, and valuable information."—*Mechanical World.*

"Admirably adapted for the purpose intended."—ED. *Mechanical Progress.*

"This unpretending publication contains a large amount of useful information in a small compass, and should be valuable to both students and engineers as an aid to memory, containing as it does numerous facts and figures on various branches of mechanical engineering. ... The notes on hydraulic machinery are especially valuable, as the author has had considerable practical experience in this branch of the profession."—*The Railroad Gazette.*

"A striking feature about the book is its exact condensation. It treats of a wide field of mechanical engineering, but it reads as if the author carefully avoided using a superfluous word. The notes are such data as would be likely to fill the pages of a practical mechanical engineer's note-book who kept his matter especially well arranged."—*American Machinist.*

"Although not intended to supersede the ordinary text-books on the subject, there is much valuable information put in a clear, brief way in this little work, and some useful tables, calculations, and formulæ are included. The subject is so wide a one that we feel sure even the experienced mechanical engineer, as well as the student, will find the work of service and be easier for reference than a more exhaustive treatise in many every-day requirements. The section devoted to the properties of materials used in mechanical engineering, and the section on the behaviour of materials under strain, the strength of beams, shafts, brackets, &c., are especially noticeable as giving concise and accurate information in an easily understood manner."—*The Manufacturer.*

"The notes in Mechanical Engineering seem to be a useful collection of rules and data, put very briefly and clearly, and so far as I have noticed, as accurate as information in such a condensed form can be."—*Professor W. C. Unwin, Examiner to Science and Art Department, and Professor of Engineering to the City Guilds.*

"The copy of your Notes in Mechanical Engineering ... has been placed in the Educational Library of the South Kensington Museum. Its title has also been sent to the agents of the Department, Messrs. Chapman and Hall, Limited, for insertion in the next edition of their catalogue of works on Science and Technology, from which selections may be made on account of Queen's Prizes awarded on the result of the May Science Examinations."—*Secretary Science and Art Department.*

"The author modestly describes his book as a supplement to a student's note-book, but the most casual glance at its contents reveals the fact that it deserves a high place amongst text-books of mechanical engineering.... The vast number of exceedingly useful formulæ given by Mr. Adams is readily get-at-able by means of a copious index of subjects, which will not only make the book of immense importance to students, but will earn for it a place in the reference libraries of experienced engineers. From the simplicity with which each note is given, we would cordially recommend this excellent little work to all users of power; and cannot conclude without saying a word for the neat enduring manner in which the book is bound."—*The Inventors' Record and Industrial Guardian.*

"I consider the book of much value as a concise set of notes on the subject, that saves hunting through a dozen volumes for some small item."—*N. C. Ray, Loco. Engr. Union Pacific Ry. Co.*

"It appears to me to strike a happy medium between the text-book and the pocket-book."—*A. N. Somerscales, Science Teacher.*

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HANDBOOK

FOR

MECHANICAL ENGINEERS.

SECTION I.

FUNDAMENTAL PRINCIPLES OF MECHANICS.

1. Force and Matter.

Motion is change of place.

Velocity is motion considered in relation to time.

Force is that which produces or destroys motion, or which tends to produce or destroy it; or which alters or tends to alter its direction.

Matter is that which is the subject of motion or a tendency to motion.

If one force only acts upon a body, motion must ensue. Forces in equilibrium are called pressures or reactions. Pressures and resistances are the active and passive states of force; in whatever direction they are exerted they may be measured in lbs., and when exerted through any given space may be measured in foot-lbs. Force may be measured by the pressure it produces upon some obstacle, and compared with gravity, or by the motion which it produces in a body in a given time. Uniform motion is when a body continues to pass over equal spaces in equal times.

2. Indestructibility of Matter.

Matter is indestructible. The atoms composing it may enter into new combinations, or may be subjected to new conditions, but no variation can be made in the absolute quantity of matter in the universe.

3. Particles, Molecules, and Atoms.

Particles are the smallest visible or tangible portions of the mass.

Molecules are the smallest physical portions of matter retaining the properties of the bulk.

Atoms are the ultimate indivisible portions of matter, probably spherical and less than the one-hundred-millionth of an inch in diameter.

In chemically compound substances a molecule must consist of atoms of all the component elements of the substance, in their proper relative proportions. In chemically simple substances the atoms probably exist in combination as molecules, various combinations producing the phenomena of allotropism and isomorphism.

4. Solids, Liquids, and Gases.

In solids the molecules are relatively fixed, in liquids they are coherent but not fixed, in gases they are repellent to each other. Hence solids press downwards only, liquids press downwards and sideways, gases press in all directions.

The pressures are the effects of gravity only, when the substances are unconfined.

5. Attraction of Cohesion and Adhesion.

Attraction of cohesion is the molecular attraction between the particles of the same body.

Attraction of adhesion is the physical attraction of the

particles of dissimilar bodies in opposition to the force of cohesion.

Capillary attraction is a form of adhesion, and the term capillarity includes all effects depending upon the adhesion or repulsion between fluids and solids.

6. Force of Gravity.

Gravity is the attraction one body has for another, and, being proportional to the mass of the body, the attraction of the earth practically overwhelms all others. The direction of attraction is towards the centre of the mass, hence, under the action of gravity, all bodies tend to fall towards the centre of the earth.

Accelerating Force of Gravity is the velocity imparted to bodies falling near the surface of the earth, in lat. 45° = 32·17 ft. per sec., say $32 \cdot 2 = g$.

Paris	.. ..	lat. 48° 50′ = 32·1819
Greenwich	..	„ 51° 29′ = 32·1912

7. Density, Mass, and Weight.

Density is the quantity of matter, or units of mass, in a unit of volume.

Mass is the quantity of matter in a body of any volume, and is constant at all heights and in all latitudes = density × magnitude.

Masses of different substance are equal when the same force acting upon them for the same time produces the same velocity.

Weight is the mass × force of gravity, which is only constant at the same level and same latitude, $\therefore$ $W \propto m\,g$, and $m = \dfrac{W}{g}$. The weight is proportional to the mass, but varies inversely as the square of the distance from the

earth's centre. The weight of a body is the resultant of its gravity towards all other bodies of the universe compounded with its centrifugal force.

Mass is independent of weight. A body carried from the equator to a pole remains unchanged as to mass, but gains $\frac{1}{2}$ per cent. as to weight.

A body weighs at sea-level, $\frac{1}{295}$ less at the equator than in London; due partly to centrifugal force, and partly to difference in distance from centre of gravity of the earth, i.e. its centre.

A body weighing 200 lbs. at equator weighs 201 lbs. at poles; $\frac{1}{3}$ of this increase is due to shorter radius to centre of earth, and remainder due to absence of centrifugal force.

8. Units of Force.

A poundal, absolute unit of force, British kinetic unit, or *Gaussian unit,* is that force which acting for unit time would impart unit velocity to unit mass. If 1 lb. = unit mass, 1 sec. = unit time, 1 ft. per sec. = unit velocity, then force in poundals = pressure of $\frac{1}{g}$ lb.

The *metrical absolute unit of force* is the force that, acting on the mass of one cubic centimetre of water at maximum density, 4° C. (mass of gramme) for one second, generates in it a velocity of one centimetre. This is also called the *dyne,* or *metrical kinetic unit.*

British gravitation units of force, or lbs., $\div$ 32 = British absolute units of force, or poundals.

9. Work and Energy.

Work may be defined as a continued motion accompanied by a continuous pressure, = weight $\times$ space passed through vertically; or pressure exerted $\times$ space passed

through in any direction. Briefly, *Work* is done when *Resistance* is overcome.

A unit of work (U) is the power expended when a pressure of 1 lb. is exerted through a space of 1 foot.

A horse-power (Jas. Watt) is the exertion of 33,000 units of work or foot-lbs. in the period of 1 minute.

Energy (Dr. Young) in mechanics means capacity for performing work, and is measured in foot-lbs.

Potential energy (Rankine), *Statical energy* (Thomson), *Sum of the tensions* (Helmholtz), or *Positional energy*, is the product of the effort or pressure into the distance through which it is capable of acting.

Actual energy (Rankine), *Kinetic energy* (Thomson and Tait), or *Accumulated work* of a moving body, is the product of the mass of the body into half the square of its velocity, or the weight of the body into the height from which it must fall to acquire its actual velocity. $U = \frac{1}{2} m v^2 = \frac{W v^2}{2 g}$.

Work done in raising a body of materials (as in building a house) = work done in raising whole weight to height of centre of gravity.

10. Vis Viva and Inertia.

Vis viva (Leibnitz), or *Energy of motion* of a moving body, is the product of the mass of the body into the square of its velocity, or double the actual energy $= m v^2 = \frac{W v^2}{g}$, the units of work being $= \frac{W v^2}{2 g}$.

Inertia, improperly called *vis inertiæ* or force of inactivity, implies the absolute passiveness of matter, or a perfect indifference to rest or motion, i.e. any change of state must arise from the action of external force.

11. Momentum.

Pressure (f) applied to a body of given mass (m) free to move, and continued for some definite time (t), causes motion at a certain velocity (v).

$$v \propto f t, \qquad f t = m v, \qquad f t = \frac{W v}{g}, \qquad f = \frac{W v}{g t},$$

or the effect varies inversely as the time occupied, and directly as the mass or weight moved and the velocity of movement.

When the body is already moving with velocity (v) and it is increased to (v_1), then

$$f t = m v_1 - m v. \qquad s = \tfrac{1}{2}(v + v_1)\, t.$$

Momentum or *Quantity of motion* = mass × velocity, and represents the constant force which acting for one second would stop a moving body = $m v$.

Moving force, or the *Moving quantity of a force*, is the momentum generated in one second.

The term momentum has been applied indifferently to express the quantity of motion existing in a body and its striking force or power of overcoming resistance, but the latter is more properly denoted by *vis viva*.

Momentum varies as the velocity.

Vis viva varies as the square of the velocity.

In its technical (workshop) use the term momentum signifies the same as actual energy or accumulated work, and is independent of time.

$$\text{Energy} = \frac{m v^2}{2} = f s. \qquad \text{Impulse} = m v = f t.$$

$$\text{Average force} = \frac{m v^2}{2} = \frac{m v}{t}.$$

12. C.G.S. System.

Upon the c.g.s. system, or centimetre-gramme-second system, one unit of work is called one "erg," and Joule's equivalent equals 42 million ergs, or 1 foot-lb. = 5444 ergs.

13. Inertia and Momentum.

As understood by practical engineers, *Inertia* is resistance to communication of motion, *Momentum* is resistance to extinction of motion. They are equal to each other, and of opposite character.

They are compared with *Work* by ascertaining h necessary to create the v under action of g, and considering W as moved through h, giving result in foot-lbs.

$$= \frac{W v^2}{2 g}, \text{ or } W h, \text{ since } h = \frac{v^2}{2 g}.$$

In calculating the power exerted in moving a load, as a truck on a railway, we have the inertia overcome in reaching the velocity attained $\left(\frac{W v^2}{2 g}\right)$ added to the work done transporting the load through the space passed over ($W \mu s$).

In coming to rest the inertia is given up again as momentum. The value of the momentum is irrespective of the distance in which the velocity was acquired; its effect depends entirely upon the distance in which it is expended.

14. Convertibility of Energy.

All forms of energy (as light, heat, and mechanical work) are mutually convertible. They are "modes of motion," and consist of *waves*, the direction of displacement of each vibrating particle varying in each case. Actual energy

of any form being once existent cannot be annihilated; it can only be transferred into some other form, or to some other matter.

15. Conservation of Energy.

The total energy of any body or system of bodies is a quantity which can neither be increased nor diminished by any mutual action of these bodies, though it may be transformed into any of the forms of which energy is susceptible.—*Clerk Maxwell.*

16. Laws of Motion.

Summary:
- I. Change of state is due to external force.
- II. Every force produces its own result.
- III. Action and reaction are equal.

First Law of Motion (Kepler, also ascribed to Galileo). All motion is naturally rectilinear and uniform. A body at rest will continue at rest, and if in motion will continue to move in a straight line with uniform velocity, unless acted upon by some external force.

Second Law of Motion (Galileo). If a body be acted upon by two or more forces for a given time, the effect will be the same as if the forces acted independently for the same length of time. This is the foundation of the parallelogram of forces.

Third Law of Motion (Newton). Action and reaction are equal. When a body receives motion from another, the second body loses a quantity of motion equal to that which the first receives. When a pressure produces motion, the quantity of motion, or momentum generated in a given time, is proportional to the pressure.

17. Equilibrium

May be stable, unstable, indifferent, or mixed.

When a body is resting on another, in such a position

that its centre of gravity is the lowest possible, it is in stable equilibrium: e. g. when vertically under the point upon which it is supported. When the highest possible, it is in unstable equilibrium: e. g. when vertically over point of support. When constant for any position, the equilibrium is indifferent: e. g. a sphere. When stable with regard to movement in one direction, and unstable or indifferent with regard to another direction, it is said to be in a position of mixed equilibrium: e. g. a cylinder lying on its side.

18. Centre of Gravity

Is that point in a body through which the resultant of the gravities (or weights) of its parts passes, in every position the body can assume.

The centre of gravity of two weights, or areas, A, B, placed l distance apart, will be x distance from A when

$$x = \frac{B}{A + B} l.$$

The centre of gravity x of a number of bodies in a straight line with regard to any point A at one end of line, W being the weight and y the distance of W from A,

$$A\,x = \frac{W\,y + W_1\,y_1 + W_2\,y_2 + \&c.}{W + W_1 + W_2 + \&c.}$$

Bodies in same plane but not in same line must be referred to co-ordinate axes. Bodies not in same plane must be referred to co-ordinate planes.

The centre of gravity is not necessarily situated in the solid portion of a body, or enclosed by its surfaces, it is simply the mean central point of the mass.

19. Centroid, or Centre of Gravity of Form.

Triangle. Bisect two sides, draw to opposite angles, intersection = c.g.

Trapezium. Divide into two triangles, find c.g. of each and join them. Divide into two triangles in the other direction, find c.g. of each and join them. Intersection of c.g. lines = mean c.g.

Tapered Girder Web.

t = thickness top,
b = " bottom,
h = height.

$$\text{Height of c.g.} = \tfrac{1}{3} h \left(\frac{2t + b}{t + b}\right).$$

Retaining Wall, vertical back.

$$\text{Height of c.g.} = \tfrac{1}{3} h \left(1 + \frac{t}{t + b}\right).$$

$$\text{Distance of c.g. from face at foot} = \frac{2b}{3} - \frac{t^2}{3(t + b)}.$$

Tee Iron ⊥. a = area lower part.
A = " upper "
d = total depth.
t = thickness.

$$\text{Height of c.g. from lower edge} = \tfrac{1}{2} \left(d + t - \frac{a\,d}{A + a}\right).$$

20. Centrifugal Force

Is the amount required to restrain a body travelling in a circle from flying off at a tangent, and is therefore perpendicular to the curve or tangent at each point.

The centrifugal force varies as the square of the angular velocity into the radius of the centre of gravity of the section on one side of axis.

Centrifugal force in absolute units = $m\,v^2/r$, in gravitation units = $W\,v^2/g\,r$.

Centrifugal force from the earth's rotation acts in opposition to gravity at the equator, and diminishes towards the poles, where it is entirely absent.

21. Centre of Gyration

Is that point in a revolving body, at which, if the whole mass were collected, the accumulated work per revolution would remain the same. It is also such that the same angular velocity would be generated in the same time by a given force at any place as would be generated by the same force acting similarly on the body itself. It is measured from the centre of revolution.

Circular wheel, uniform thickness	$= r\sqrt{\frac{1}{2}} = \cdot 7071\, r.$
Rod revolving about its extremity	$= l\sqrt{\frac{1}{3}}$
„ „ centre ..	$= l\sqrt{\frac{1}{12}}.$
Flywheel rim	$= \sqrt{\frac{R^2 + r^2}{2}}.$
Solid sphere	$= r\sqrt{\frac{2}{5}} = \cdot 6325\, r.$
Wire ring, revolving about a diam.	$= r\sqrt{\frac{1}{2}}.$
Thin circular plate „ „	$= \cdot 5\, r.$
Thin hollow globe	$= r\sqrt{\frac{2}{3}} = \cdot 8165\, r.$
Solid sphere revolving round an external axis at c distance from centre of sphere	$= \sqrt{c^2 + \frac{2}{5} r^2}.$
Cylinder round its axis	$= r\sqrt{\frac{1}{2}}.$
„ „ parallel external axis	$= \sqrt{c^2 + \frac{1}{2} r^2}.$

22. Centre of Oscillation

Is that point in a vibrating body, in which, if the whole mass were collected, the body would continue to vibrate through the same angle; and such that any force applied there would generate the same angular velocity in a given time as the same force at the centre of gravity, the parts of the body or system revolving in their respective places.

r = radius to centre of gravity.
R = " " gyration.
R_1 = " " oscillation.

$$R_1 = \frac{R^2}{r}.$$

The centre of oscillation is interchangeable with the centre or point of suspension, which then becomes the centre of oscillation.

23. Centre of Percussion

Is that point in a body revolving about an axis, at which, if it struck an immovable obstacle, all its motion would be destroyed, or it would not incline either way: it is that point with which, if the body strike against any obstacle, no shock will be felt at the point of suspension: it is the same point in a body as the centre of oscillation.

24. Centre of Spontaneous Rotation,

Or spontaneous gyration, is that point which remains at rest when a body is struck, or about which it begins to revolve.

25. Parallelogram of Forces.

If three forces act in a plane upon a free point which remains at rest, they may be represented in direction and magnitude by three lines, two of which form adjacent sides of a parallelogram and the third is equal and opposite to the diagonal.

26. Equilibrium of Forces.

Forces acting upon a body at rest, but free to move, are said to be in equilibrium.

27. Sense of Forces.

The word *sense* has been introduced recently to assist the word *direction* in dealing with forces; direction may be looked upon as relating to the *position of the line*, and sense as relating to the *position of the arrow head* with regard to the line.

28. Triangle of Forces.

The three lines described under "parallelogram of forces" will also form a triangle, the arrow heads pointing all the same way round.

29. Polygon of Forces.

When more than three forces in one plane acting upon a point are in equilibrium they may be represented in magnitude and direction by lines forming a closed polygon. More fully defined in next paragraph.

30. Force Polygon.

When forces acting upon a point are represented by concurrent lines to form a polygon, open or closed, part of which may overlap other parts, it is called the *force polygon*, and when unclosed requires a closing line, representing a new force, known as the *equilibrant*, to balance the remainder. The *resultant* of a number of forces is equal and opposite to their equilibrant. The resultant of any number of forces does not depend upon the order in which they are drawn as the sides of the polygon, provided their *senses* are concurrent.

31. Link Polygon.

When forces act together in a system but not through one point, their leverage or turning moment through a

point or pole is found by means of the ***link polygon*** or ***funicular polygon*** of the forces, which gives the position of the resultant force, otherwise unattainable.

The link polygon is obtained by drawing the force polygon and selecting any point (internal or external) for a pole, drawing lines from the pole to the junctions of the sides of the force polygon, and constructing a new polygon with sides parallel to these lines, commencing at any point on one of the force lines in its original position, and each side terminating upon meeting the direction of the next force, at which point the next side will commence. The resultant force passes through the last intersections, the direction, sense, and magnitude being taken from the force polygon.

32. Composition and Resolution of Forces.

Composition of forces takes place when a ***resultant*** is substituted for two or more component forces.

Resolution of forces takes place when a single force is replaced by two or more forces equivalent to it, and is the reverse of the former case.

33. Moment of a Force.

The product of a force and the perpendicular distance of its direction from any given point, is termed the moment of the force about that point. The moment of a resultant about any point is equal to the sum of the moments of the components about that point.

The term pound-feet is used for moments in leverage, and must not be confused with foot-pounds of energy. "Pound-feet" belongs to statics, "foot-pounds" to dynamics.

34. Principle of the Equality of Moments.

When a body is in equilibrium the sum of the moments of any number of forces that tend to turn the body in one

direction is equal to the sum of the moments of any number of forces that tend to turn the body in the opposite direction.

35. Principle of Least Resistance.

Moseley (1833). "If there be a system of forces in equilibrium, among which are a given number of resistances, then is each of these a minimum, subject to the conditions imposed by the equilibrium of the whole." Used chiefly in finding line of resistance in arches.

36. Specific Gravity

Of a body is the ratio of its density to that of some standard substance, generally water or air.

The standard for solids is pure distilled water at 60° Fahr., weighing 1000 oz. per cub. ft. = $62\frac{1}{2}$ lbs.

The standard for gases and vapours is atmospheric air at 60° Fahr., 30 ins. bar., weighing 31 grains per 100 cub. ins. = ·07 lbs. per cub. ft.

W = weight of substance in air.
W_1 = " " water.
V = volume "
S = specific gravity of substance.
w = weight of unit of standard.

$$W = V\,S\,w. \qquad S = \frac{W}{V\,w}. \qquad S = \frac{W}{W - W_1}.$$

37. Statics and Dynamics.

Statics is the science of forces in equilibrium, or pressures.

Dynamics or *kinetics* is the science of forces not in equilibruim, i.e. those producing motion.

38. Theory of Machines.

Machines are mechanical arrangements for transmitting force and utilising it in a convenient manner. Power is a constant sum consisting of pressure and movement, or force and velocity, either of which may be increased with a corresponding reduction of the other. The common phrase, "what is gained in power is lost in speed," would be less liable to misapprehension if the word *pressure* were substituted for *power*.

39. Mechanical Powers.

More properly called *Mechanical elements*, or *Simple machines*, commonly described as seven, but all referable to two of the number, thus:—

Lever:—
- Wheel and axle
- Toothed wheels
- Pulley .. ..

} Modifications of the lever.

Inclined plane:—
- Wedge.. ..
- Screw .. ..

} Modifications of the inclined plane.

Lever.—Three orders; fulcrum, weight, and power, alternately between the other two, principle identical.

$$Px = Wy \therefore P = \frac{Wy}{x},\ W = \frac{Px}{y},\ x = \frac{Wy}{P},\ y = \frac{Px}{W},$$

or, taking weight of lever into account,

$$Px = Wy + W'y'.$$

[illegible]hen a [illegible] numb[illegible]t levers the length is measured from the fulcrum [illegible]endicular to the direction of the force.

Wheel and Axle.—Same principle, taking radius as leverage.

Toothed Gearing.—Ditto.

Pulleys.

n = number of cords shortened by raising the weight

$$\frac{W}{n} = P, \text{ or motion of } W : \text{motion of } P :: P : W.$$

Inclined Plane.

$$L : H :: W : P \quad \therefore \quad P = \frac{H}{L} W.$$

Wedge.—$L : t :: W : P$ (P being direct pressure without friction).

Percussion and friction must be considered in any practical calculation.

Screw.—R = radius of lever, p = pitch of screw.

$$2\pi R : p :: W : P.$$

Differential Screw.

$$2\pi R : p' - p :: W : P.$$

Endless Screw or Worm.

N = number of teeth in wheel.
n = „ threads in worm.
R = radius of handle or power.
r = „ axle or weight.

$$RN : rn :: W : P.$$

40. Steelyards, &c.

Roman Statera.—Lever of first order, balance-weight movable.

Common Steelyard.—Similar, but with two fulcra on opposite sides of beam, and two corresponding sets of divisions.

Danish Balance.—Fixed balance-weight at one end, fulcrum movable.

Common Balance or Scales.—Arms equal, substance counterpoised by equivalent loose weights.

Bent Lever Balance.—Fulcrum fixed, counterbalance constant, virtual length of arms altered by movement due to weight of substance.

Spring Balance.—Weight indicated by amount of tension or compression upon a spring.

Pooley's Weighing Machine.—System of compound levers on principle of Roman Statera.

Duckham's Weighing Machine.—Weight indicated by increase of pressure upon enclosed liquid.

41. Useful Work of Men in Foot-Pounds per Minute.

Working for	10 hours per day.	8 hours per day.	6 hours per day.
Raising own body	—	4250	—
Working treadmill	—	3900	—
Drawing or pushing horizontally	—	3120	—
,, ,, vertically	—	2380	—
Turning handle	—	2600	—
Arms and legs, as rowing	—	4000	—
Wheeling material on ramp	720	—	—
Throwing earth up 5 feet	470	—	—
Raising material with pulley	—	—	1560
,, ,, ,, hands	—	—	1470
Carrying do. on back, returning empty ..	—	—	1126

42. Comparison of Animal Power.

Horse	22,000	ft.-lbs. per minute.
Mule = $\frac{2}{3}$ horse	14,667	,, ,,
Ass = $\frac{1}{5}$,, ...	4,400	,, ,,
Man = $\frac{1}{10}$,, ...	2,200	,, ,,

43. Formulæ for Falling Bodies.

h = Height of fall in feet.
v = Velocity in feet per second.
g = Force of gravity = 32·2.
t = Time of fall in seconds.
H = Highest point reached in feet.
T = Time to reach ditto.
V = Velocity imparted otherwise than by gravity.

Falling from Rest.

$$h = \frac{g\,t^2}{2} = \tfrac{1}{2}\,g\,t^2 = \frac{v^2}{2g},$$

$$v = g\,t = \frac{2\,h}{t} = \sqrt{2\,g\,h},$$

$$t = \frac{v}{g} = \frac{2\,h}{v} = \sqrt{\frac{2\,h}{g}},$$

Thrown Downward.

$$h = V\,t + \tfrac{1}{2}\,g\,t^2,$$

$$v = V + \sqrt{2\,g\,h} = V + g\,t,$$

$$t = \frac{2\,h\,g + V^2 - V\,v}{g\,v}.$$

Thrown Upward.

$$h = V\,t - \tfrac{1}{2}\,g\,t^2 = \frac{V^2}{2\,g}, \qquad H = \frac{V^2}{2\,g},$$

$$v = V - \sqrt{2\,g\,h} = V - g\,t, \qquad V = \sqrt{2\,g\,H},$$

$$t = \frac{2\,h\,g + V^2 + V\,v}{v\,g}, \qquad T = \frac{V}{g}.$$

Every uniformly accelerated motion acting freely is subject to similar laws.

44. Rolling on Inclined Planes.

In rolling a body down an inclined plane, the final velocity, omitting friction, is dependent solely on the height passed through, and will be the same as if falling freely. The average velocities will therefore be the same

in descending all planes of equal height, and the times of descending will be proportional to the length.

A body will fall down all chords of a vertical circle to the lowest point in the same time.

45. Brachystochrone, or Curve of Quickest Descent.

An inverted semi-cycloid with its base passing through the starting point, and its vertex passing through the terminal point, is the curve of quickest descent; a circular arc with its centre on a vertical line through the terminal point is next, and a straight line joining the extremities is the slowest although the shortest route. From whatever part of the cycloid the body commences its descent it will always occupy the same time in reaching the bottom.

46. Velocity of Sound.

Sound travels in air

at 62° F., about 1125 ft. per sec.
at 32° F. „ 1090 „ „

Sounds of varying intensity, pitch, or quality (timbre) travel at the same velocity.

Sound travels in iron 17, wood 17 to 11, water $4\frac{1}{2}$ times faster than in air. —*Tomlinson.*

47. Relative Velocities.

Falling body	32	ft. per sec.
Race-horse	50	„ „
Fast train	90	„
Cannon-ball	1,700	„ „
Gun-cotton (flame)	15,000	„ „
Earth in orbit	95,000	„ „
Meteorite	250,000	„ „
Light	1,100,000,000	„ „

—*Prof. Dewar.*

SECTION II.

VARIETIES AND PROPERTIES OF MATERIALS.

48. Varieties of Iron.

Wrought Iron.—Fibrous — Tough — Soft — Ductile at high temperatures, but not fluid—Pressed in moulds at 1500° to 2000° F.—Welded at 2500° to 2800° F.—Easily oxidised—Forged, hammered, or rolled to various shapes —Contains very little carbon.

Steel.—Fibrous to granular—Containing small amount of carbon may be welded, and with more carbon may be cast—Can be forged—Very tough and strong—May be tempered—Special properties due to some extent to silicon—Used chiefly for tools.

Cast Iron.—Crystalline—Brittle—Fluid at high temperatures—Takes complicated shapes by casting in a mould —Contains much carbon—The various qualities known as Nos. 1, 2, 3.

Colours to represent them upon drawings:—

Wrought iorn	Blue (Prussian blue).
Steel	Purple (Violet carmine).
Cast iron	Grey (Payne's grey).

49. To Distinguish Wrought Iron, Steel, and Cast Iron.

If made red hot and hammered, cast iron or malleable cast iron will fly to pieces. If plunged in water while red hot, steel will harden, while wrought iron will remain soft. They are also distinguished by the grain of the fractured surface. A drop of nitric acid on bright steel will produce a black spot, while wrought iron remains bright; the darker the spot the harder the steel.

50. Effect of Carbon in Iron.

No.	Name.	Percentage of Carbon.	Properties.
1	Malleable iron	0·25	Is not sensibly hardened by sudden cooling.
2	Steely iron ..	0·35	Can be slightly hardened by quenching.
3	Steel	0·50	Gives sparks with a flint when hardened.
4	„	1·00 to 1·50	Limits for steel of maximum hardness and tenacity.
5	„	1·75	Superior limit of welding steel.
6	„	1·80	Very hard cast steel, forging with great difficulty.
7	„	1·90	Not malleable hot.
8	Cast iron ..	2·00	Lower limits of cast iron, cannot be hammered.
9	„ ..	6·00	Highest carburetted compound obtainable.

—*Bauerman.*

51. Common Ores of Iron.

Oxides:—

Magnetic Oxide, or Magnetite—from Sweden, Norway, North America, &c.

Red Hæmatite, or Kidney Ore—from Whitehaven and Ulverston.

Specular Iron Ore—is same composition, but composed of crystallised masses; found in Russia, Spain, Elba, &c.

Brown Hæmatite—differs from Red Hæmatite in having water in its composition; from Forest of Dean, Alston Moor, Northamptonshire, &c.

Carbonates:—

Spathose Iron Ore, Spathic Ore, or Iron Glance—from Northumberland and Durham.

Argillaceous:—

Clay Ironstone or Clay Band—from South Wales, Dudley, North Staffordshire, Yorkshire, &c.

Black Band Ironstone—from Ayrshire and Lanark, containing coaly impurities.

52. Roasting and Smelting.

Ore broken into pieces, mixed with coal in large heaps, and allowed to burn slowly to drive off water, carbonic acid gas, and sulphur. Called calcining or roasting.

Roasted ore, with earthy matters to form a flux, and fresh fuel to maintain heat, are smelted together in a *blast furnace*, 50 to 100 feet high, to obtain the metal from the ore. Charge consists of say 5 cwt. ore, 2 cwt. limestone, 5 cwt. coke, repeated every half hour, furnace being kept full. Molten metal run off every 12 hours into channels in sand, long lines called *sows*, branches 3 or 4 feet long called *pigs*. Furnace not blown out for 6 or 7 years, unless under special circumstances.

53. Chemical Action of Blast Furnace.

The silica, alumina, and lime in the ore and flux combine by the aid of heat to form a glassy slag, which floats on the molten metal and runs off near the bottom of the furnace. A small portion of the carbon combines with the iron and keeps it fluid until drawn off at the tap-hole. The remainder of the carbon of the fuel combines with the oxygen in the ore and the blast to form carbonic oxide ("fire-damp," burning with blue flame) and carbonic acid ("choke-damp"), which pass out at the top.

54. Pig Iron.

Hot-blast and Cold-blast.—Named from the temperature of the blast used in smelting the ores. Hot-blast generally

quicker and more economical, requiring only 30 cwt. of coke per ton of metal instead of 40 cwt., but the metal is not considered to be so strong. Difficult to distinguish the two varieties, but, other circumstances being equal, hot-blast iron has rather a finer grain, duller fracture, with sometimes patches of coarse grains, and usually more impurities. Increasing the blast or reducing the supply of fuel makes the iron whiter, harder, and less suitable for re-melting, but better for conversion into wrought iron or steel.

55. Analyses of Pig Irons.

Description.	C	Mn	Si	S	P
Foundry— Glengarnock ..	3·677	1·777	2·40	·602	1·010
Bessemer— Workington ..	4·941	·065	1·572	·038	·007
Swedish— Lily	4·603	1·276	·070	·006	·015
Spiegels.					
Ebbw Vale	3·734	8·958	·215	·064	·088
J. Brown and Co.'s ..	4·675	25·12	·445	·002	·056
Ferro-manganese ..	6·588	65·13	·187	·081	·059

56. Classification of Pig Iron.

Bessemer Iron.—A variety of pig iron made from hæmatite ores for conversion into steel; very free from impurities.

Foundry Iron.—All pig iron having grey fracture and large proportion of uncombined carbon; produced under high temperature and full supply of fuel.

Forge Iron.—White pig iron, almost free from uncombined carbon, suitable for conversion into wrought iron; produced with low temperature or insufficient fuel, frequently run from blast furnace into iron moulds, rendering it brittle for ease in breaking up.

57. Refining

Is a combination of chemical and mechanical processes by which pig-iron is deprived of its impurities previously to its conversion into wrought iron.

Refining consists simply of melting the pig iron with coke or charcoal in an open hearth or "refinery furnace," supplied with an air blast so as to impinge on the melted metal and furnish an oxidising atmosphere. This carries off a portion of the carbon, and at the same time removes a portion of the impurities, particularly silicon, in the form of slag. The melted metal, having lost some of its carbon, is then poured into a cast-iron trough kept cold by water, and the sudden chilling has the effect of converting soft grey iron into hard silvery-white metal, the carbon which formerly existed in the shape of graphite entering into perfect chemical combination. By this change the fluidity of the iron is reduced, and the subsequent puddling process facilitated.

The loss of weight in refining crude iron averages 10 per cent., and the weekly production of a refinery furnace is from 80 to 160 tons.

58. Puddling.

Dry Puddling is the process of obtaining wrought iron by burning the carbon out of refined cast iron in a reverberatory furnace. The oxygen of the air, at the high temperature employed, combines with the carbon to form carbonic oxide gas, which escapes. In hand-puddling the

mass is stirred about until it is of sufficient tenacity to be lifted out of the furnace in balls or blooms of 60 to 80 lbs. each; in Danks' rotary furnace the revolution of the furnace effects the same as the hand labour.

If the operation be stopped before the carbon is all removed, puddled steel is obtained.

Wet Puddling or *Pig-boiling* is the more modern process, in which grey unrefined pig iron is converted direct. The bed of reverberatory furnace is lined with broken slag, cinder, scale, &c., fused together, and over these a fettling of soft red hæmatite or "puddlers' mine" is placed. The stages of the puddling process are—(1) graphitic carbon converted into combined carbon, and silicon partly oxidised by roasting and melting; (2) metal drawn from sides, and mixed with that in centre; (3) metal "boiled" for twenty minutes, impurities being oxidised by agitation of the mass; (4) pasty metal "balled" and re-balled, ready for shingling.

59. Squeezing, Shingling, and Rolling.

After removal from the puddling furnace, at a welding heat, the blooms are put under a heavy trip hammer, a rotary squeezer, or a hydraulic press, to remove the slag and impurities from the spongy mass, and to solidify the metal. They are then passed through chilled rolls, flat or grooved, of various dimensions, to produce the shape required, being drawn down gradually to the finished size.

60. Crude Wrought Iron.

Puddled Bar is the material after passing a bloom through the first series of rolls.

Merchant Bar is made by cropping, piling, re-heating, welding, and rolling puddled bar.

Single, double, and treble best signifies the number of times the material is again put through these processes.

61. Qualities of Wrought Iron.

(*a*) Iron easily worked hot, and hard and strong when cold, used for rails.

(*b*) Common iron, used for ships, bridges, and sometimes for shafting.

(*c*) Single, double, and treble best iron, from Staffordshire and other parts where similar qualities are made. The single or double best is used for boilers. Double and treble best are used for forging.

(*d*) Yorkshire iron, from Lowmoor, Bowling, or other forges where only fine qualities are made. The best Yorkshire iron is very reliable, and uniform in quality. It is used for tyres, for difficult forgings, for furnace plates exposed to great heat, for boiler plates which require flanging, &c.

(*e*) Charcoal iron, very ductile and of best quality.

—*Unwin's 'Machine Design.'*

62. Single and Double Sheet Iron.

Iron sheets, up to No. 20 B.W.G. inclusive, are called *singles;* Nos. 21 to 24, *doubles;* Nos. 25 to 28, *lattens;* and, above No. 28, *extra lattens.* Singles are less than $\frac{3}{16}$ in. in thickness, and when the sheets are less than about $\frac{1}{30}$ in. they are too thin to be rolled separately, therefore two are placed together.

63. Iron Rolling Mills.

Weight of piles to produce boiler plates, allowing for waste in the furnace and waste in shearing:—Add for every $\frac{1}{16}$ in. in thickness 1 lb. 1 oz. to every square foot of plate over and above the finished weight.

To make boiler plates from slabs, allow one-third more than the weight of finished plate ; and for re-heating and doubling, 5 lb. to every 100 lb. more than one-third must be allowed.

For plates narrower than 20 inches an allowance of 10 lb. extra to every 100 lb. must be made for greater waste from shearing.

To make sheets from piles varying from 11 to 30 wire gauge, add one-half more than the finished weight, which is sufficient for waste and shearing upon both bar and sheet.

For merchant bars of all kinds, which are rolled from the pile in one heat, one-fifth more than the finished weight is sufficient to allow for waste and cropping.

As regards wages, the ironworker is paid per ton long weight. What is termed long weight is 2400 lbs. to the ton.—*Mechanical Progress.*

64. Defects in Wrought Iron.

Cold-shortness is produced by the presence of a small quantity of phosphorus as an impurity. The iron is brittle when cold, but of ordinary character when heated. It cracks if bent cold, but may be forged and welded at high temperatures.

Red shortness is generally produced by the presence of sulphur, sometimes by arsenic, copper, and other impurities. The iron is tough when cold, but cannot be welded, and is difficult to forge at high temperatures.

65. Case-hardening.

When polished wrought iron is heated to a cherry red and placed in contact with broken prussiate of potash (K_4FeCy_6), scraps of leather, &c., the surface is converted

into steel by absorption of carbon, and is then hardened by quenching in water. The nitrogen in the mixture is supposed to play an important part.

Other nitrogenous matters, such as bone-dust, horn, hoof, and hide clippings, are often used. If heated with the mixture in a close box, the effect is greater. The case-hardening may extend to a depth of about $\frac{1}{16}$ inch. The surface shows a mottled appearance before re-polishing.

This method of hardening is used largely for motion blocks, links, pins, and eyes, and generally for small articles or portions of them which have to stand much friction. It is cheaper than using steel, but the tendency of the articles to crack and twist is an objection.

66. Casting Wrought Iron.

In the "Mitis" process (Nordenfelt's) a small amount of aluminium, say $\frac{1}{2000}$ to $\frac{1}{700}$ by weight, is added to Swedish wrought iron, which causes it to melt and flow at a temperature insufficient to cause the occlusion of gases, and sound tough castings are obtained, having all the properties of the best forged iron, except that they are perfectly homogeneous and free from stratification. Mitis metal will weld and harden. Made by Hansell and Co., Canal Steel Works, Sheffield.

67. Varieties of Steel. No. 1.

Steel may be made by the addition of carbon to wrought iron, or the abstraction of carbon from cast iron; both methods are in use commercially.

Blister steel is produced by a process called cementation. Bars of purest wrought iron are placed in a furnace between layers of charcoal powder, and kept at a high temperature for from 5 to 14 days. The bars are now brittle, crystalline, and more or less covered with blisters. Small regular blisters and fine grain denote good quality. Used for

facing hammers, &c., but not for edge tools; used largely for conversion into other kinds of steel.

Spring Steel is blister steel heated to an orange-red colour, and rolled or hammered.

68. Classification of Blister Steel.

No. 1.	Spring heat	$\frac{1}{2}$	per cent.	of carbon.
„ 2.	Country heat ..	$\frac{5}{8}$	„	„
„ 3.	Single-shear heat	$\frac{3}{4}$	„	„
„ 4.	Double-shear heat	1	„	„
„ 5.	Steel-through heat	$1\frac{1}{4}$	„	„
„ 6.	Melting heat	$1\frac{1}{2}$	„	„

—*Seebohm.*

69. Varieties of Steel. No. 2.

Shear Steel is blister steel cut into short lengths, piled into faggots, sprinkled with sand and borax, and placed at welding heat under a tilt hammer. "Single" and "double" shear steel denotes the number of times this process is repeated. Fibrous character now restored. Used for large knives, scythes, plane irons, shears, &c., frequently in conjunction with iron.

Crucible Cast Steel.—Originally made by melting fragments of blister steel in covered fireclay crucibles, and running into iron moulds. Now generally made direct from Swedish bars cut up and placed in crucibles, with small quantity of charcoal, with subsequent addition of spiegeleisen or oxide of manganese. Variations on this process are known as Heath's and Mushet's, also Tungsten steel, Chrome steel, &c. Forged at low heat, unweldable, fracture grey, crystals very minute.

70. Varieties of Steel. No. 3.

Bessemer Steel.—Made from grey pig-iron containing a large proportion of free carbon, small quantity of silicon and manganese, free from sulphur and phosphorus. Iron

melted in cupola, and run into a converter lined with fire-brick and suspended on hollow trunnions. Air blown through the metal about twenty minutes, removing all carbon ; 5 to 10 per cent. spiegeleisen then added, and blowing resumed long enough to incorporate the two metals. Steel then run out into ladle and moulds. Ingots being porous are reheated and put under steam hammer, then rolled or worked as required. Used for rails, tyres, common cutlery and tools, roofs, bridges, &c.

Siemens Steel.—Pig-iron melted on furnace hearth; good ore and limestone are then added and heat kept up, process resulting in carbonic acid gas, slag, and steel.

71. Varieties of Steel. No. 4.

Siemens-Martin Steel.—Pig iron melted in furnace, three or four times its weight of heated wrought iron scrap or steel added, together with spiegeleisen or ferro-manganese, until required proportion of carbon, &c., is obtained, to give steel of requisite hardness; then run into ingot moulds.

Landore-Siemens Steel.—Iron ore is treated in a rotatory furnace with carbonaceous material, and converted into balls of malleable iron, which are transferred direct to steel-melting furnace. Spiegeleisen, &c., then added. The result is steel of very ductile quality, dense and uniform in texture, and particularly suitable for replacing wrought iron where increased strength is required, in addition to all the best properties of wrought iron.

72. Varieties of Steel. No. 5.

Galy-Calazat Steel.—Superheated steam is forced through the molten metal, thus oxidising the carbon, and also removing the sulphur and phosphorus as sulphuretted and phosphoretted hydrogen. Used in France.

Heaton Steel.—The melted metal is acted on by certain salts, such as nitrate of soda, &c., by which the carbon is oxidised out. Henderson employed fluorides, and Bell, oxide of iron.

Thomas and Gilchrist, Gilchrist-Thomas, or *Basic Steel* (1879).—Similar to Bessemer, but difference in the lining of the converter, which is basic or non-siliceous, made from burnt dolomite or magnesian limestone. Phosphorus eliminated quickly and cheaply by combining with the lime; the resulting slag containing phosphorus used as manure when pulverised. The phosphorus being removed by this process, inferior iron may be used.

73. Dannemora Cast Steel.

Carbon.	Temper.	Tools suited for	Remarks.
per cent. $1\frac{1}{2}$	Razor.	Turning and planing, drills, &c.	Great skill required in forging, spoilt if overheated.
$1\frac{1}{4}$	Turning tool.	Turning, planing, and slotting tools, drills, small cutters, and taps.	Not weldable.
$1\frac{1}{8}$	Punch.	Mill picks, circular cutters, taps, rimers, small shear-blades, large turning-tools and drills, punches, and screwing dies.	May be welded with great care.
1	Chisel.	Cold chisels, hot setts, medium-size shear-blades, large punches, large taps, miners' drills for granite.	Will weld with care.
$\frac{7}{8}$	Sett.	Cold setts, minting dies, large shear-blades, miners' drills; smiths' tools, as sett hammers, swages, flatteners, fullers, &c.	Will weld without difficulty.
$\frac{3}{4}$	Die.	Boiler-cups, snaps, hammers, stamping and pressing dies, welding steel for plane-irons, &c.	Will weld like iron.

74. "Eidsfos Stöbestaal" Cast Steel.

Quality.	Percentage Carbon. Prof. Eggertz' method.
For turning and planing tools for metals	1·55 to 2·00
,, slotting and boring tools	1·45 ,, 1·55
,, cold chisels, &c.	1·25 ,, 1·45
,, edge tools, joiners' tools, &c.	1·10 ,, 1·25
,, mining tools, fine springs, twist drills, and for tools requiring toughness	0·90 ,, 1·10
,, buffer springs, axles, shafts, tools requiring great toughness, &c...	0·75 ,, 0·90
,, gun barrels, and for tools requiring the greatest degree of toughness	0·40 ,, 0·75

75. Relative Pig-iron and Steel Production of different Countries.

	Tons Pig-iron.	Tons Steel.
Great Britain	7,750,657	1,988,045
United States	4,044,526	1,711,920
Germany and Luxemburg	3,751,775	1,200,000
France	1,628,941	527,048
Austria and Hungary ..	760,000	225,752
Belgium	714,677	146,189
Russia	498,000	300,000
Sweden	430,504	74,241
Spain	126,269	10,000
Italy	24,778	3,450
All other countries	150,000	30,000

—*Martineau and Smith.*

76. Notes on Cast Iron.

Stronger in compression than wrought iron, but much weaker in tension. Not so safe as wrought iron when subjected to impact or suddenly applied loads.

Used for complex parts of machines, because easier to mould in casting than wrought iron in forging. Principally for wheels, bed-plates, and framings.

If thickness of different parts varies much, the castings will be strained in cooling. All edges should be well rounded and hollows filleted.

Expands at moment of solidification in casting, but contracts in cooling. Contraction varies with size and thickness of casting, and quality of metal.

77. Qualities of Cast Iron.

No. 1. *Grey.*—Soft. Deficient in strength. Used for ordinary castings. Very fluid when melted. 0·6 to 1·5 per cent. carbon chemically combined, 2·9 to 3·7 per cent. mechanically combined.

No. 2. *Mottled.*—Variable hardness. Stronger than No. 1. Used for larger castings. More carbon chemically combined, and less mechanically.

No. 3. *White.*—Hard. Fusible. Strong. Used for conversion into wrought iron. 3 to 5 per cent. of carbon all chemically combined.

These varieties are mixed in various proportions for special purposes.—*Unwin's 'Machine Design.'*

78. Chilled and Malleable Cast Iron.

Chilled Cast Iron is ordinary cast iron rapidly cooled during solidification, by using a mould of white or hard cast iron for the part requiring to be chilled, protected by

a wash of loam, causing a chemical combination of the molten iron and carbon. Very hard. Fracture silvery. Direction of crystallisation strongly marked.

Malleable Cast Iron is made by heating ordinary castings, preferably of white cast iron, from two to forty hours, according to size, in contact with oxide of iron or powdered red hæmatite, causing partial conversion into wrought iron by abstraction of carbon.

79. Toughened Cast Iron.

Toughened cast iron is produced by adding to the cast iron, and melting amongst it, from one-fourth to one-seventh of its weight of wrought-iron scrap, which removes some of the carbon from the cast iron, and causes an approximation to steel.—'*Notes on Building Construction*,' iii. 252.

80. Copper.

Very malleable, and hence specially suited for hammering into thin hemispherical pans, rolling into sheets, &c., also ductile to a less degree. Rendered brittle by absorption of carbon, refined and toughened during manufacture, but may be spoilt again by careless manipulation. May be cast. Can be forged cold, or at red heat, but rapidly scales when hot. Addition of 2 to 4 per cent. of phosphorus improves its fluidity and tenacity. Used for fire-boxes, &c., because it is a good conductor of heat, but loses tenacity in proportion to its temperature. Much used in forming alloys.

81. Aluminium.

Aluminium, by the Deville-Castner process, is made at $\frac{1}{3}$ of its former price, and for many of the lighter parts of

mechanism or delicate machinery may shortly become a substitute for the more common metals, as it does not tarnish even when exposed to damp and impure air.

82. Alloys.

Bronze is a mixture of (say) 10 copper, 1 tin.

Brass is a mixture of (say) 2 copper, 1 zinc.

The terms "higher" and "lower" applied to brass express the greater or less quantity of zinc in the composition. High brass consists of 2 copper to 1 zinc. Low brass 4 copper to 1 zinc.

Gun-Metal is a mixture of copper, tin and zinc in various proportions, according to the hardness or toughness required: say 16 copper, 2 tin, 1 zinc. May be also called bronze.

Muntz-Metal is a mixture of 3 copper, 2 zinc, and is therefore a brass.

Alloys generally fuse at a lower temperature than the average of the component metals.

83. Effect of Alloying with Copper.

Tin increases the hardness, and whitens the colour through various shades of red, yellow, and grey.

Zinc in small quantity increases fusibility without reducing the hardness, in greater quantity increases malleability when cold, but entirely prevents forging when hot.

Lead increases the ductility of brass, and makes alloy more suitable for turning, filing, &c.; in large quantity causes brittleness.

Phosphorus increases the fluidity and tenacity, reduces the effect of the atmosphere, and allows of tempering.

84. Bronze Alloys.

Name.	Copper.	Tin.	Zinc.
Soft gun-metal	16	1	..
Mathematical instruments	12	1	..
Pumps (very tough)	32	3	1
Pump plungers	14	1	1
Small toothed wheels	10	1	..
Locomotive bearings	64	7	1
Engine bearings	112	13	½
Locomotive straps and glands	130	16	1
Admiralty mixture for valves and mountings..	90	10	2½
Hard gun-metal for bearings	8	1	..
Baily's metal	32	5	2
G. M. for heavy bearings	32	5	1
Maximum hardness for bearings.. ..	5	1	..
Hydraulic valve faces	4	1	..
Tam-tam (Chinese gongs)	4	1	..
Bell metal	4 or 3	1	..
Speculum metal	2	1	..

85. Brass Alloys.

Name.	Copper.	Zinc.	Tin.	Lead.
Tough for engine work ..	100	15	15	..
For turning and fitting ..	3	1	..	$\frac{1}{12}$
Soft for hammering	7	3	..	..
Yellow brass	2	1	..	..
Stop cocks and valves	88	10	2	..
Flanges for brazing	32	1	..	1
Brass for soldering	8	3	..	..
Brass, various	60–92	8–40	½–3	½–3
Muntz-metal sheathing ..	3	2	..	..
Do. locomotive tubes.. ..	66	33	..	1
Nails for sheathing	87	4	9	..
Statuary bronze	90	5	2	..
Red brass (Tombak)	8–10	1	..	..
Red sheet brass (German) ..	11	2	..	..
Bronze for lamps	27	6	1	1

86. Antimony Alloys.

Name.	Copper.	Tin.	Lead.	Antimony.	Bismuth.
Babbitt's metal ..	1	10	..	1	..
Do. lining do. ..	1	24	...	2	..
Antifriction do. ..	1	50	..	5	..
Expanding alloy ..	..	..	..	2	1
Pewter	..	100	..	17	..
Type metal	..	..	3 to 7	1	..
Stereotype metal ..	..	..	77	15	8
White brass	1	..	7	7	..
Do.	3	90	..	7	..

87. Nickel Alloys.

Name.	Copper.	Zinc.	Nickel.	Iron.
Common German silver.. ..	60	25	15	..
Better do.	50	25	25	..
Chinese Packfong	55	17	23	3
Argentan, for hammering or rolling	40·4	25·4	31·5	2·6
Argentan, for plating	62	19	13	4 to 5
Do. hard	57·4	25	13	9
Electro	8	3·5	4	..
Solder for German silver (coarsely powdered)	8	7·5	4	..

88. Various Alloys.

Name.	Copper.	Tin.	Zinc.	Various.
Silver-bell metal ..	80	10	6	4 lead.
Pot or cock metal ..	5	..	..	2 lead.
Ship nails..	10	..	8	1 iron.
Cowper's metal ..	..	2	..	1 bismuth.
Aluminium bronze ..	90	..	..	10 aluminium.
Sterro-metal	60	2	35	3 wrought iron.
Gedge's metal	60	..	38·2	1·8 " "
Delta metal	55½	½	41½	1 lead, 1 iron, ⅜ manganese.
Phosphor bronze ..	82	10	..	7½ lead, ⅛ iron, ⅛ nickel, ¼ phosphorus.

89. Fusible Alloys.

Melting point.	Lead.	Tin.	Bismuth.	Zinc.
deg. Fahr.				
212	1	3	5	..
246	1	4	5	..
286	..	1	1	..
334	..	2	1	..
336	2	3	..	..
392	..	8	1	..
442	..	1	..	..
472	..	..	1	..
612	1	..	..	..
648	..	..	..	1

—*Tredgold.*

90. Alloys Fusible below 212° F.

Melting point.	Lead.	Tin.	Bismuth.	Zinc.	Mercury.	Cadmium.
212	5	3	8	..	..	..
210	4	3	8	..	..	..
203	31	19	50	..	..	..
200	1	1	4	..	..	..
149	28·5	17	45·5	..	9	..
138	8	4	15	..	..	3

91. Solders.

Name.	Tin.	Lead.	Copper.	Zinc.
Plumbers' fine solder	1	1	..	..
„ coarse „	1	3	..	..
Tinmen's fine „	3	1	..	..
„ coarse „	2	1	..	..
Spelter hard „	..	..	3	2
„ soft „	..	..	1	1

92. Melting Points of various Metals, &c.

Platinum	(?) 8500° Fahr.
Wrought iron	3250 to 4300
Steel	3250 to 4100
Cast iron	2200 to 2750
Copper	2000
Gun-metal	1900
Yellow brass	1850
Aluminium	1800
Antimony	810
Zinc	750
Lead	620
Bismuth	480
Tin	440
Wax	150
Tallow	100
Water	32
Mercury	− 38

When a substance $\left\{\begin{array}{c}\text{expands}\\ \text{contracts}\end{array}\right\}$ in the act of fusion, the solid parts will $\left\{\begin{array}{c}\text{sink}\\ \text{rise}\end{array}\right\}$ in the liquid. Such substances have their temperature of fusion $\left\{\begin{array}{c}\text{raised}\\ \text{lowered}\end{array}\right\}$ while under pressure. Example $\left\{\begin{array}{c}\text{cast iron}\\ \text{water}\end{array}\right\}$.

93. Expansion of Metals by Heat.

In fractions of each dimension for one degree Fahrenheit.

Wrot. iron	·00001235	Steel	·00001145
Cast iron	·00001127	Brass	·00001894

Copper	·00001717	Platinum ..	·00000884
Lead	·00002818	Glass	·00000861

—*Perry.*

Water expands $\frac{1}{22}$ of its bulk from 32° F. to 212° F. From 32° F. to 572° F. iron expands $\frac{1}{227}$, copper $\frac{1}{177}$.

94. Weight of various Metals in Pounds.

Name.	Cubic inch.	Cubic foot.
Gold	·70	1203
Lead	·41	710
Copper	·32	550
Gun metal	·31	530
Brass	·30	525
Muntz metal ..	·29	510
Steel	·28	490
Wrought iron ..	·28	480
Tin	·26	460
Cast iron	·26	450
Zinc	·25	435
Aluminium ..	·09	160

Multipliers to reduce Cubic Ft. to Tons.

Wrought iron .. .. ·2143.
Steel .. .. ·2175.
Cast iron .. .. ·2009.

95. Use of Wood in Engineering.

Pattern-making.—American yellow pine, New Zealand pine, mahogany, alder, sycamore.

Bearings.—Lignum vitæ (end grain).

Brake Blocks.—Willow, poplar.

Pulley Sheaves.—Lignum vitæ, box.

Buffer Beams.—Oak.

Floats for Paddle-wheels.—Willow, American elm, English elm.

Sluice Paddles.—Oak, greenheart.

Wheel Teeth.—Hornbeam, beech, holly, apple, oak if in damp place.

Joiners' Tools.—Beech, box.

Hammer Shafts.—Ash (cleft).

Tool Handles.—Ash, beech.

Shafts and Springs.—Ash, hickory, lancewood.

Ordinary framing, piling, &c.—Yellow deal, Memel, Riga, or Dantzic (creosoted for outdoor work).

Carriage-building.—Teak.

Fender and Rubbing pieces.—American elm.

Scaffold Poles.—Spruce, fir.

Earth Waggons and Barrows.—Elm.

Rough Gangways.—White deals.

96. Fir, Deal, and Pine.

Fir is a general term for wood used in the rough, as distinguished from

Deal, a general term for wood wrought and used by the joiner.

Pine is another general term used for even grained stuff suitable for panels. Also for pitch pine.

Yellow deal and red deal are botanically classed as pine.

White deal and spruce deal are botanically classed as fir.

Deal is not a botanical term.

Planks, deals, and battens, are trade terms for boards of certain widths, viz. planks 11 inches, deals 9 inches, battens 4½ to 7 inches.

SECTION III.

STRENGTH OF MATERIALS AND STRUCTURES.

97. Classification of Strains.

Tension	Stretching or pulling.
Compression	Crushing or pushing.
Transverse Strain	Cross strain or bending.
Torsion	Twisting or wrenching
Shearing	Cutting, or when acting along the grain of timber, detrusion.

98. Definitions of Strain and Stress.

Strain.—Every load which acts on a structure produces a change of form, which is termed the strain due to the load. The strain may be temporary or permanent, the former disappearing when the load is removed, the latter remaining as permanent set.

Stress.—The molecular forces, or forces acting within the material of a structure, which are called into play by external forces, and which resist its deformation, are termed stresses.—*Unwin's 'Machine Design.'*

Thus the *strength* of a piece in a given position may be such that a *load* of so many *lbs.* produces a *stress* of so many *lbs. per sq. in.*, the result being a *strain*, or change of form of a certain amount, whether temporary or permanent, and, when large enough, appearing as stretching, shortening, bending, crumpling, or twisting.

99. Proof Strength.

It was formerly supposed that the proof strength of any material was the utmost strength consistent with perfect elasticity; that is, the utmost stress which does not produce a *permanent set.* Mr. Hodgkinson, however, ha

proved that a set is produced in many cases by a stress perfectly consistent with safety. The determination of proof strength by experiment is now, therefore, a matter of some obscurity; but it may be considered that the best test known is, *the not producing an increasing set* by repeated application.—*Rankine's 'Applied Mechanics.'*

100. Factor of Safety

Is an amount fixed by practical experience, varying with the material used, and the manner of using. It is the ratio of the greatest safe stress to the ultimate resistance of the material, such as $\frac{1}{4}$, $\frac{1}{10}$, &c., and the calculated resistance of any section multiplied by the factor of safety suitable to the circumstances, will give the safe working load.

If structures never deteriorated they might be loaded to one-third of their breaking weight with perfect safety, but to guard against ordinary contingencies one-fourth of the breaking weight is the maximum permanent load allowable under any circumstances.

101. Testing Wrought Iron.*

The strength of a bar should be measured by the *work* done in producing rupture, i.e. the product of the elongation into the mean stress. A convenient approximation to relative toughness is obtained by observing the maximum stress and the elongation in a given length. The length formerly taken was 8 inches, but $6\frac{1}{4}$ inches is now usually adopted, so that the increase of length in sixteenths of an inch will represent the elongation per cent. The elongation being principally local, the percentage specified for a length of 8 inches $\times$ $\frac{128}{100}$ or $1 \cdot 28$, will give the proper percentage for a length of $6\frac{1}{4}$ inches.

* See leaflet by the author on 'The Behaviour of Materials under Strain.'

102. Usual Allowance for Dead Load per Square Inch Sectional Area.

	Breaking Strain.	Safe Load.
Wrought Iron—		
Tension	22 tons	5 tons
Compression	18 „	4 „
Shearing	20 „	4 „
Mild Steel—		
Tension	28 „	7 „
Rivets in shear	24 „	6 „
Cast Steel—		
Tension	35 „	8 „
Compression	50 „	12 „
Cast Iron—		
Tension	7 „	1½ „
Compression	42 „	7½ „
Shearing	15 „	3½ „

The compression and shearing values assume that the parts are unable to bend.

103. Maximum Working Strength in Tons per Square Inch.

	Constant Load.	Variable Load.	
Wrought Iron for Machinery.	Tension only 5. Compressn. only 4.	Tension only 3. Compressn. only 2½.	Alternate Tension and Compression 1½.
Mild Steel for Machinery.	Tension only 8. Compressn. only 12.	Tension only 5. Compressn. only 7½.	Alternate Tension and Compression 2½.
Cast Iron for Machinery.	Tension only 1¼. Compressn. only 6.	Tension only ¾. Compressn. only 4½.	Alternate Tension and Compression ⅜.

104. Comparative Strength of Iron and Steel Plates.

Quality.	Ultimate tensile strength in tons per sq. in.		Elongation per cent.	
	With Grain.	Across Grain.	With Grain.	Across Grain.
Mild steel	30	28	20	18
Best Yorkshire ..	24	22	12	7½
B. B. Staffordshire	22	19	9	5
B. "	20	18	6	2½

105. Tests of Iron and Steel.

Physical.

Brand.	Point of permanent set in tons per square inch.	Tension in tons per sq. inch.	Elongation. per cent.
Lowmoor	—	25·50	42·15
Staffordshire	16·82	25·57	27·50
Mild steel	17·92	28·86	45·00
Medium steel	20·87	33·25	35·92
Hard steel	25·60	39·84	30·50
Tool steel	—	57·68	14·40
Very hard steel	—	68·67	7·00

Chemical.

Brand.	C.	Mn.	Si.	P.	S.
Parkhead common iron .	·09	trace	·020	·316	·027
Leeds Forge best iron ..	·14	·03	·110	·085	·028
Bowling best iron	·11	trace	·10	·101	trace
Farnley best iron	·11	·01	·090	·096	·012
Lowmoor best iron ..	·10	·01	·120	·142	·022
Landore mild steel ..	·18	·64	·013	·077	·074
Mild steel	·22	·399	·062	·043	·042
Medium steel	·34	·536	·024	·052	·019
Tool steel	·97	·148	·074	·034	·059

106. Shearing Strength Compared with Tensile Strength.

Is variable, but averages for

Wrought iron	85 per cent.	Mild steel	81 per cent.
Cast iron	40 „	Hard steel	64 to 70 „

—*Platt and Hayward.*

107. Modulus of Rigidity

Is the ratio between the shear stress, in lbs. per square inch, and the shear strain, or movement of a particle in inches at one inch from the fixed end.

$$\frac{\text{stress}}{\text{strain}} = \text{N}.$$

The torsional resistance of any material is proportional to the modulus of rigidity.

108. Limit of Elasticity.

The maximum strain per square inch sectional area, which any material can undergo without receiving a visible permanent set, is called its limit of elasticity, or elastic strength.

The average limits of elasticity are—

Wrought iron, 10 tons. Cast iron, 2 tons. Steel 15 tons.

And the average elongations under a strain of 1 ton per square inch are—

Wrought iron $\frac{1}{10000}$. Cast iron $\frac{1}{7500}$. Steel $\frac{1}{13000}$.
—*Anderson.*

Wrought iron $\frac{1}{12000}$. Cast iron $\frac{1}{6000}$. Steel —
—*Kennedy.*

109. Fatigue of Wrought Iron.

When repeatedly strained beyond its elastic limit, wrought iron takes an increasing permanent set, and ultimately breaks with less than its original maximum load; but if periodically annealed before rupture takes place, its elasticity may be renewed. This loss of strength, *being recoverable*, may be termed *fatigue.*

110. Modulus of Elasticity.

A bar in tension or compression is elongated or shortened by an amount proportionate to the stress within certain limits. Assuming the elongation, on increasing the stress, to continue in the same ratio, a certain point would be reached where the bar would be increased to twice its original length. The weight in lbs. per square inch sectional area of the bar, to produce this result, is the modulus of elasticity. The amount depends upon the kind and quality of the material employed, and may vary 50 per cent.

111. Definitions of Modulus of Elasticity.

The modulus of direct elasticity of a material is the ratio of the stress per unit of section of a bar, to the elongation or compression per unit of length, produced by the stress —*Unwin's 'Machine Design.'*

It is the weight in lbs. that would stretch or compress a bar, having a sectional area of one square inch, by an amount equal to its own length called Hooke's law—*Cargill's 'Strains.'*

When expressed in feet the modulus of elasticity gives the height to which a body would have to be piled in order that any small addition to its top, of its own substance, might compress the rest to an extent equal to the bulk of that added quantity.—*Dr. Young.*

112. Formula for Elongation by Elasticity.

E = Modulus of direct elasticity (see table).
l = Length in inches.
w = Load per square inch sectional area in lbs.
e = Elongation in inches.

$$e = \frac{w \times l}{E}.$$

Approximately :—

$$\frac{\text{W in tons} \times l \text{ in ft.}}{\text{sq. ins. area} \times 1000} = \text{E in inches for wrought iron.}$$

113. Moduli of Elasticity.

	In lbs. per sq. in.
Cast steel, tempered	36,000,000
Steel, ordinary	30,000,000
Wrought-iron bar	29,000,000
Ditto plate	25,000,000
Cast iron	18,000,000
Copper	16,000,000
Phosphor bronze	14,000,000
Gun metal	10,000,000
Brass	9,000,000
Tin	5,000,000
Lead	720,000

114. Modulus of Elasticity of Bulk.

The pressure in lbs. per sq. in. upon the exterior of any substance, or the external stress, produces a diminution of bulk per cubic inch, called the *cubical strain* of the substance. The strain is proportional to the stress, and is

equal to the stress divided by a certain number called the *modulus of elasticity of bulk*, and represented by K.

K =	Water	300,000
	Cast iron	14,000,000
	Wrought iron	20,000,000
	Steel	24,000,000
	Copper	30,000,000

115. Moment of Inertia.

The moment of inertia of a section is the summation of the areas of all its individual parts, multiplied by the squares of their distances from the neutral axis.

$$\Sigma\, a\, y^2 = \mathrm{I}.$$

—*Unwin.*

Moment of inertia is the sum of the moments of resistance in any given section.—*Hurst.*

116. Bending Moment, or Moment of Flexure,

Is the moment of the external forces on one side of a transverse section estimated relatively to the section.

$\mathrm{M} = \dfrac{\mathrm{E\,I}}{\rho}$ expresses the relation between the bending moment and the curvature of a bar under transverse strain.—*Unwin*

117. Bending Moment.

The bending moment M at a section is equal to the stress at one inch from the centre of gravity of the section multiplied by the moment of inertia I of the section.

$$\frac{\mathrm{M}}{\mathrm{I}} = \text{stress at 1 in. from neutral axis.}$$

118. Modulus of Section, or Strength Modulus,

Is a function of the dimensions proportional to the moment of resistance of the section. It is the moment of inertia divided by the distance from the neutral axis to the furthest part on the extended or compressed side.

$$Z_t = \frac{I}{y_t} \qquad Z_c = \frac{I}{y_c}.$$

Modulus of section × max. strain tension or compression = bending moment.

$$M = f_t z_t = f_c z_c.$$

—*Unwin.*

119. Moment of Rupture

Varies according to the position of load and mode of support, e.g. a beam supported at the ends and loaded in the centre.

$$M_c = \frac{W l}{4};$$

and if load be distributed

$$M_c = \frac{W l}{8}, \quad \text{or} \quad \frac{w l^2}{8}.$$

In a flanged beam $\frac{\text{moment of rupture}}{\text{depth}}$ = stress in flange.

In a beam of any section, the stability depends upon the equation—

Moment of Rupture = Moment of Resistance, or M = K.

—*Humber.*

Moment of Load is the load multiplied by its effective leverage at the point required. The moment of a load

divided by the depth of beam will give the horizontal strain on the extreme fibres in its upper and lower sides.

—*Hurst.*

120. Modulus of Rupture for Transverse Strains.

The theoretical value of this is the resistance of the material to direct compression or tension, but it is found from experiments on cross breaking that this value is, from various causes, not sufficiently high, and Professor Rankine has adopted a modulus which is 18 times the load required to break a bar of 1 sq. in. section, supported on two points 1 ft. apart, and loaded in the middle between the supports.

C =

Cast iron	40,000	Fir ..	5,000 to 10,000
Wrought iron ..	42,000	Oak ..	10,000 to 13,600

—*Humber.*

121. Moment of Resistance.

The moment of resistance of a section is the moment of inertia multiplied by the modulus of rupture and divided by the distance of the neutral axis from the furthest edge of the section.

$$R = \frac{C\,I}{y}.$$

—*Humber.*

The moment of resistance of a beam at any section is the sum of all the products obtained by multiplying the actual longitudinal stress taken at each square inch of the section by its distance from the neutral axis. The moment of resistance in a flanged girder is the longitudinal strength of the weakest flange multiplied by the mean depth of the girder.—*Perry.*

The moment of resistance in a beam is proportional to the area of the fibres multiplied by the squares of their distances from the neutral axis.—*Hurst.*

122. Working Load for given Moment of Resistance.

f = greatest safe intensity of stress.

$$\text{Let } M = \frac{W\,l}{8} = f\,z, \text{ then } W = \frac{8\,f\,z}{l}.$$

And again

$$\text{Let } M = \frac{W\,l}{4} = f\,z, \text{ then } W - \frac{4\,f\,z}{l}.$$

123. Strength of Structures.

The strength of structures varies as the square of the linear dimensions of similar parts, excluding the effect of weight; but the weight varies as the cube of the linear dimensions. The strength of a structure of any kind is not therefore to be determined by that of its model, which will always be much stronger in proportion to its size. All works, natural and artificial, have limits of magnitude which, while their materials remain the same, they cannot surpass.—*Lardner.*

124. Safe Load on Structures.

Cast-iron columns .. .. .. Cast-iron girders for tanks .. Wrought-iron structures ..	$= \frac{1}{4}$ breaking weight.
Cast-iron for bridges and floors	$= \frac{1}{6}$,,
Stone and bricks	$= \frac{1}{8}$,,
Timber	$= \frac{1}{10}$,,
Do., temporary structures ..	$= \frac{1}{6}$

—*Molesworth.*

125. Safe Load on Floors.

Churches and public buildings,	$1\frac{1}{2}$	cwt. per	sq. ft.
Warehouses	$2\frac{1}{2}$	„	„
Dwelling houses	$1\frac{1}{4}$	„	„

126. Weight of Men in Crowds.

Mr. Cowper found by experiment that a number of men averaged 140 lbs. per square foot.

Mr. Parsey considers that men packed closely would weigh at least 112 lbs. per square foot, but that in ordinary crowds 80 lbs. might be taken as sufficient.

On the Continent it is not usual to estimate so high. Belgians weigh about 140 lbs. each, Frenchmen 136 lbs. while Englishmen weigh 150 lbs.

Mr. F. Young states 80 lbs. per square foot is quite safe in practice.

Mr. Thomas Page packed picked men on a weighbridge with a result of 84 lbs. per foot super.

Mr. George Gordon Page says that for troops on march $35\frac{1}{4}$ lbs. per square foot is sufficient.

The usual practice is to assume the live load as 100 lbs. per square foot.—*A. T. Walmisley.*

127. Approximate Safe Load on Columns and Piers.

Oak post ..	up to 10 diameters long,		$\frac{3}{10}$	ton per	sq. in.
Fir „ ..	„	„	$\frac{2}{10}$	„	„
Cast-iron column or stanchion	„	„	5	„	„
Do.	10 to 15	„	4	„	„
Do.	15 to 20	„	3	„	„
Do.	20 to 25	„	2	„	„
Do.	25 to 30	„	$1\frac{1}{2}$	„	„

Hard York or Portland stone piers	12	tons per	foot super.
Stock brick in cement, if covered with stone template	6	„	„
„ „ without ditto ..	4	„	„

128. Wrought Iron Struts.

Angle, tee, or cross section, ends fixed.

l = length, inches.
d = least width, inches.
f = factor of safety = 5 to 8.

$$\text{Safe load lbs. per sq. in., sect. area} = \frac{42000}{f} - 120\frac{l}{d}$$

$$\text{,, tons ,, ,,} = \frac{20}{f} - \cdot 05\frac{l}{d}.$$

129. Notes on Iron Columns.

When the length is 26·4 times the diameter, pillars, columns, or vertical struts are of equal strength whether of wrought or cast iron; when shorter, cast iron is stronger; when longer, wrought iron is stronger.—*Gordon.*

Cast iron columns under 5 diameters long, fail entirely by crushing; from 5 to 20 diameters, partly by crushing partly by bending; over 20 diameters, entirely by bending.

130. Strength of Cast Iron Columns.

Cast iron hollow columns:—

d = external diameter inches ($\frac{1}{10}$ to $\frac{1}{30}$ length).
t = thickness in inches, (not to exceed $\frac{1}{6}$ d).
L = length in feet (ends flat and fixed).

$$\text{Safe load tons per sq. in.} = (t + 1)\frac{2\,d}{L}.$$

Cast iron solid columns:—

W = breaking weight tons per sq. in.
r = ratio of length to least diam.

$$W = \frac{42}{1 + \cdot 003\, r^2}$$

—*Planat.*

131. Pillars and Struts of Wood.

d = diam. or width narrowest side, inches.
F = crushing force, short specimen, tons per sq. in.
l = length in inches.
S = sectional area, sq. ins.
W = breaking weight in tons.

$$W = \frac{F\,S}{1 + \dfrac{l^2}{100\, d^2}} \qquad F = \begin{cases} \text{Oak } 3 \cdot 2. \\ \text{Fir } 2 \cdot 5. \end{cases}$$

—*Rankine.*

W = safe load tons total.
a = sectional area, sq. in.
d = least diam. or width side, ins.
L = length, feet.

$$W = 1 \cdot 0752\, a \frac{d^2}{L^2} \text{ or } W = \begin{cases} \cdot 45\, a \text{ for oak.} \\ \cdot 27\, a \text{ for fir.} \end{cases}$$

The lesser value to be taken. If unseasoned, the safe load will only be one-half above.

Approx. safe load on fir post:—

$$\frac{b \text{ ins.} \times d \text{ ins.} \left(60 - \dfrac{l \text{ ins.}}{b \text{ ins.}}\right)}{250} = \text{safe load, tons.}$$

132. Approximate Weight of Timber Roofs.

King or Queen truss, span in feet^2	= lbs. per truss.		
Common rafter and purlins	= 7 lbs. per ft. sup.		
$\frac{3}{4}$-inch slate boarding	= $2\frac{1}{2}$	,,	,,
Slate battens	= $1\frac{1}{4}$	,,	,,
Roofing felt	= $\frac{1}{2}$	,,	,,
Slates and nails (general)	= 9	,,	,,
Ceiling (complete)	= 12	,,	,,
Snow	= $7\frac{1}{2}$	,,	,,
Wind (horizontally)	= 56	,,	,,

The combined effect in vertical load with trusses usual distance apart may be taken at 60 lbs. per ft. sup.

133. Weight of Materials for Estimating.

Wrought iron	480 lbs. per cub. ft.		
Cast iron	450	,,	,,
Gun-metal and brass	530	,,	,,
Cast steel	504	,,	,,
Mild steel	490	,,	,,
Lead	700	,,	,,
Copper	550	,,	,,
Zinc	450	,,	,,
Greenheart	60	,,	,,
Oak	50	,,	,,
Fir	40	,,	,,
Granite	160	,,	,,
Bramley Fall and Hard York	140	,,	,,

134. Sheet Copper.

Sheets 4 feet by 2 feet.

B.W.G. 22	=	1·25 lbs per ft. sup.		
24	=	1·0	,,	,,
26	=	·75	,,	,,
28	=	·5	,,	,,

135. Sheet Lead.

Cast sheets, 6 feet wide × 16 to 18 feet long.
Milled sheets, 7 feet wide × about 25 feet long.
Made 3 to 10 lbs. per ft. sup.

Lbs. per foot × ·017 = thickness in decimals of an inch.

136. Sheet Zinc.

Sheets 2 ft. 8 in. and 3 ft. wide, 7 ft. and 8 ft. long.

No. 10 gauge	=	$11\frac{1}{2}$	oz. per	ft. sup.
12 „	=	$15\frac{1}{8}$	„	„
14 „	=	$18\frac{3}{4}$	„	„
16 „	=	$24\frac{3}{4}$	„	„

137. Handy Numbers for Weight of Iron.

Wrought:—

Sectional area, square inches × $3\frac{1}{3}$ = lbs. per foot run.
Cubic inches × ·28 = lbs.
Round iron, $d^2 \times 2 \cdot 62$ = lbs. per foot run.
Square feet per $\frac{1}{8}$ inch thick × 5 = lbs.
For weight of rivets in plate girders, take 5 per cent. of weight of plates and angle irons.

Cast:—

Weight of wrought − 5 per cent. = weight of cast.
23 cubic inches = 6 lbs.

Mild Steel:—

Weight of wrought iron + 5 per cent. = weight of mild steel.

138. Limits of Ordinary Prices, Staffordshire District.

Plates.—Weight 5 cwt., length 15 feet, width 4 feet 30 feet super, shape regular.

Angle and Tee Irons.—Length 40 feet, size $2\frac{1}{2}$ inches by $2\frac{1}{2}$ by $\frac{1}{4}$ up to 8 united inches.

Bars.—(Round and square), diameter $\frac{1}{2}$ inch to 3 inches, length 25 feet.

Bars.—(Flat), size 1 inch by $\frac{1}{4}$ inch up to 6 inches by 1 inch, length 25 feet.

139. Extract from the Cleveland List of Limits and Extras.

Weight, to 10 cwt. Beyond, 10*s*. per ton for every cwt. or portion thereof.

Length, to 20 feet. Beyond 2*s*. 6*d*. per ton per foot or part thereof.

Width, 12 inches to 54 inches. For $\frac{3}{16}$ inch and $\frac{1}{8}$ inch thick, 12 inches to 48 inches. Beyond or under, 5*s*. per ton per inch or part thereof.

Area { 60 square feet for thicknesses from $\frac{1}{4}$ inch to to 1 inch inclusive.
48 „ „ $\frac{3}{16}$ inch thick.
36 „ „ $\frac{1}{8}$ inch „

Beyond (if sellers undertake them at all), 1*s*. per ton per square foot.

Boiler plates, except B B B boiler, 48 square feet.

„ „ B B B boiler, 36 square feet.

Beyond (if undertaken) 2*s*. 6*d*. per ton per square foot.

Thickness, $\frac{1}{4}$ inch to 1 inch. $\frac{3}{16}$ inch 10*s*. per ton, and $\frac{1}{8}$ inch 30*s*. per ton extra.

Sketches, 20*s*. per ton. Curved sketches, 40*s*. per ton. 4 inch taper allowed before counting sketch.

Guarantee.—In case of serious defect, or error in dimensions, a plate will be replaced, and on receipt of the rejected one the amount originally charged will be credited. Dimensions will be worked to as nearly as practicable, but absolute exactness must not be expected. No further liability is undertaken by sellers except by special contract.

Stoppage of Works.—Should the works of the makers or buyers be stopped by a strike, or by accident to machinery or buildings, current contracts to be suspended during such interruption but not to be thereby cancelled.

—*Fox, Head, & Co.*

140. Deflection and Camber.

Deflection is the displacement of any point in a loaded beam, from its position when the beam is unloaded.

Camber is an upward curvature, similar and equal to the maximum calculated deflection, given to a beam or girder or some line in it in order to ensure its horizontality when fully loaded.

141. Deflection.

Radius of curvature of neutral axis of a beam at any section when under transverse stress—

$$= \frac{E\,I}{M}.$$

142. Radius of Curvature

Is the radius of the circle coinciding most nearly with a curved line or portion of one.

Curvature is the reciprocal of this radius. Thus, if radius be 100 feet, curvature is $\frac{1}{100}$. If radius alters

further on to 120 feet, the change of curvature will be $\frac{1}{100} - \frac{1}{120} = \frac{1}{600}$.

The curvature of a circle is inversely proportional to its radius, and is measured by the fraction $\frac{1}{\text{radius}}$.

—*Goodeve.*

143. Deflection of Girders.

In girders with parallel flanges of uniform strength, the deflection produces a circular curve, the amount of deflection varies directly as the load × the sum of the areas of both flanges × the cube of the length, and inversely as the area of top flange × area of bottom flange × depth of web squared, or

$$\Delta = \frac{W \times (a_t + a_b) \times l^3}{a_t \times a_b \times d^2} \times c.$$

$c =$	Wrought iron.		Cast iron.
Load centre ..	·016	..	·025.
Load distributed	·01	..	·018.

Common Rule.—Girders to be constructed with a camber of $\frac{1}{4}$ to $\frac{1}{2}$ inch per 10 feet of span, to allow for deflection when loaded.

Feet span × ·005 to ·0075 = safe deflection in inches under ordinary loads.

Feet span × ·02 to ·03 = safe deflection in inches under special loads.

American practice. Feet span × ·01 = safe deflection in inches after permanent set.

Board of Trade allows $\frac{3}{4}$ inch per 100 ft. span (= $\frac{1}{1600}$ = ·0075) for deflection caused by maximum rolling load beyond the deflection due to maximum dead load.

144. Deflection Tests.

Two main girders 60 ft. span erected in yard with cross girders and bearing for railway viaduct. Weight complete, one span with temporary timber, 22 tons.

Deflection in centre	with	30 tons	distributed	= ·32 in.
,,	,,	60	,,	= ·685 ,,
,,	,,	90	,,	= 1·085 ,,
,,	,,	121·5	,,	= 1·53 ,,
,,	,,	do. & 10 tons centre		= 1·73 ,,
,,	,,	loads removed		= ·47 ,,

145. Formula for Deflection of Wrought Iron Flanged Girders

Of uniform strength, supported at both ends, and carrying distributed load. Strain allowed = 5 tons per square inch tension, 4 tons per square inch compression.

s = Span in feet.
d = Mean depth in inches.
Δ = Deflection in inches in centre.

$$\Delta = \frac{\cdot 0144\, s^2}{d}.$$

If depth $= \frac{1}{10}$ span, $\Delta = \cdot 012\, s$; $\frac{1}{12} = \cdot 0144\, s$; $\frac{1}{15} = \cdot 018\, s$.

146. Deflection of Solid Beams.

Δ = Deflection in inches.
l = Length in feet.
b = Breadth in inches.
d = Depth in inches.
W = Load in cwts. in centre.

c = Constant =

Cast steel	650	Quebec oak ..	40
Wrought iron ..	550	Fir and deal ..	33
Cast iron	330	Dantzic oak ..	27
Teak	50	Pitch pine ..	25

Rectangular beam—

$$\Delta = \frac{l^3 W}{b\, d^3\, c}, \qquad W = \frac{\Delta\, b\, d^3\, c}{l^3},$$

$$b = \frac{l^3 W}{d^3\, \Delta\, c}, \qquad d = \sqrt[3]{\frac{l^3 W}{\Delta\, b\, c}}, \qquad b\, d^3 = \frac{l^3 W}{\Delta\, c}.$$

Square beam, side $= \sqrt[4]{\dfrac{l^3 W}{\Delta\, c}}$.

Cylindrical beam, diameter $= \sqrt[4]{\dfrac{^3 W}{\Delta\, c}} \times 1\cdot 7$.

If load be uniformly distributed, deflection = $\frac{5}{8}\Delta$.
Cantilever with distributed load = Δ 6.
Cantilever loaded at end = Δ 16.
Safe deflection in timber = $\frac{1}{480}$ length, or $\frac{1}{40}$ inch per foot span.

147. Coefficients for Deflection—Rectangular Beams.

Δ =		δ =	
Wrought iron	·000002	Fixed one end, loaded the other	128
Cast iron ..	·000003	„ load distributed ..	48
Steel	·0000016	Supported ends, load central ..	8
Oak	·0000375	„ load distributed ..	5
Ash	—	Fixed both ends, load central ..	2
Fir	—	„ load distributed	1

$$\text{Deflection} = \frac{W \text{ lbs.} \times l^3 \text{ ft.} \times \delta \times \Delta}{b \text{ ins.} \times d^3 \text{ ins.}}$$

General formula for beams of uniform section, fixed one end, loaded the other, deflection $\Delta = \frac{W l^3}{3 E I}$.

148. Coefficients of Reaction for Deflection.

		Box.	*Unwin.*
Fixed one end, loaded the other ..	K =	32	16
,, load distributed ..	=	12	6
Supported both ends, load central ..	=	1	1
,, load distributed	=	$\frac{5}{8}$	$\frac{5}{8}$
Fixed both ends, load central	=	$\frac{2}{3}$	—
,, load distributed ..	=	$\frac{5}{12}$	—

149. Specification Tests of Cast Iron.

Three bars, each 3 feet 6 inches long, 2 inches deep, and 1 inch wide, to be cast on edge in dry mould from each melting at which any of the specified work is cast. These bars to be tested separately as follows:—The lower side of the casting to be placed downwards* upon rigid bearings, with 3 feet clear span, each bar to deflect not less than $\frac{3}{10}$ inch with a load of 25 cwt. in centre having a bearing not more than 1 inch wide upon the bar, to break with a minimum load of 28 cwt. and an average upon the three bars of not less than 30 cwt.

Samples prepared in lathe to bear $2\frac{1}{2}$ tons per square inch tensile strain before loss of elasticity, and to break with not less than 7 tons per square inch.

* Placed the other way up a reduction of about 15 per cent. in the apparent strength may occur.

150. Specification Tests of Wrought Iron (Bridge and Girder Work).

Class.	Tons. per square inch, tensile strength.	Elongation* per cent. at twenty tons.	Contraction per cent. at point of fracture.
Rivet iron	25	10	30
Rod and bar iron ..	24	7½	20
Angle and tee iron ..	22	6	15
Plates, with grain ..	21	4½	10
Plates, across grain ..	18	..	5

* In a length of 8 inches.

151. Allowance in Bridges for Changes of Temperature.

Variation of 15° F. alters length of wrought iron as much as strain of 1 ton per square inch.

In exposed situations an allowance of $\frac{7}{16}$ of an inch movement, per 100 feet length, is necessary for the purpose of eliminating the strains due to change of temperature.—*Graham Smith.*

152. Specification Tests—Common Wrought Iron.

Class.	Tons. per square inch, tensile strength.	Contraction per cent. at point of fracture.
Rivet iron	22	20
Rods, bars, and angles..	21	12½
Plates	20	10

—*Timmins.*

153. Specification Tests of Wrought Iron and Steel (Shipbuilding).

Class.	Tons. per square inch, tensile strength.	Elongation* per cent. on fracture.	Toughness.†
Rivet iron	26	25	650
Rod and bar iron	24	15	360
Angle and tee iron ..	22	12½	275
Iron plates, with grain	20	7½	150
" " across grain	19	6	114
Steel plates (both directions)	28	20	560
" bars and angles ..	30	25	750

* In a length of 6¼ inches.

† Should the actual elongation in sixteenths of an inch, multiplied by the stress in tons per square inch, upon rupture, be more than 10 per cent. under the amounts given in the last column, the material will be rejected.

Wrought Iron.—Cold bending in vice—½-inch plate 35°, ⅜-inch plate 55°, $\frac{5}{16}$-inch plate 63°, ¼-inch plate 70°, rivet iron to double close, without cracking.

Steel.—For Admiralty tests, *see* 'Molesworth,' p. 28.

154. Steel and Iron Shipbuilding.

Lloyd's Regulations allow a reduction of 20 per cent in the scantlings of a steel ship as compared with iron, but the total weight of material used is only about 14 per cent. less. The cost is about the same in steel or iron.

155. Ultimate Strength of various Metals and Alloys.

Name.	Tension. Tons per sq. in.	Compression. Tons per sq. in.
Mitis iron (cast)	27	..
Aluminium bronze ..	25	..
Phosphor bronze	25	..
Delta metal	23	..
Muntz metal	20	..
Malleable cast iron ..	15	45
Copper (wire)	25	..
Copper (sheet and bolt)	15	..
Copper (cast)	10	..
Gun metal	12	48
Brass	10	5
Zinc	3	..
Tin	2	..
Cast lead	$1\frac{1}{2}$	3

156. Safe Load on Timber in Direct Compression.

Fir and deal—

with the grain = 450 lbs. per sq. in.
across „ „ = 250 „ „ „

157. Formula for Strength of Timber.

s = span ft. b = breadth ins. d = depth ins.
B.w. = breaking weight cwts. centre. c = constant.

$$\text{B. w.} = \frac{b\,d^2}{s}\,c.$$

When load is not central, dividing span into x and y

$$\text{B w.} = \frac{s\,b\,d^2}{4\,x\,y}\,c.$$

Safe deflection = $\frac{1}{40}$ inch per foot span.

In calculating scantling of timber for practical use under tension or transverse stress, $1\frac{1}{2}$ inches must be added to

each dimension to allow for the contingency of a knot occurring in the piece.

When loaded on top and supported at the ends, the soundest side of a square beam should always be placed downwards, and if rectangular then the soundest of the narrow sides should be downwards.

158. Experiments on Rectangular Beams of Selected Pine.

B. w. lbs. centre $= 6080 \dfrac{b\,d^2}{l}$ (all inches) or if l in feet.

then $= 506\frac{2}{3} \dfrac{b\,d^2}{L}$.

If a given rectangular beam be under a given strain by a given load in a given position which divides the span in the proportions x and y, then to obtain the same strain when the load divides the span in the proportions m and n, the depth d will be altered to $d_1 = d \times \sqrt{\dfrac{m\,n}{x\,y}}$.

159. Ultimate Strength of Timber.

Name.	Tension. per square inch.	Compression. per square inch.
Ash	$7\frac{1}{2}$ tons	4 tons
Beech	5 „	4 „
Elm	6 „	4 „
Memel and Riga fir ..	5 „	$2\frac{1}{2}$ „
Larch	5 „	$1\frac{1}{2}$ „
Honduras mahogany ..	$4\frac{1}{2}$ „	$3\frac{1}{2}$ „
English oak	6 „	4 „
Dantzic „	$5\frac{1}{2}$ „	$3\frac{1}{2}$ „
Quebec „	$5\frac{1}{2}$ „	3 „
Teak	7 „	5 „
Pitch pine	$4\frac{1}{2}$ „	3 „
Hornbeam	4 „	$3\frac{1}{2}$ „

160. Strength and Stiffness of Timber.

Name.	Stiffness.	Strength.	Resilience.
Ash	89	119	160
Beech	77	103	138
Riga fir	98	80	64
Memel fir	114	80	56
Larch	79	103	134
Honduras mahogany ..	93	96	99
English oak	100	100	100
Dantzic "	117	107	99
Quebec "	114	86	64
Teak	126	109	94
Pitch pine	73	82	92

Oak being taken for comparison as = 100.

161. Resilience.

Resilience or *Spring* is the quantity of mechanical work required to produce the proof-stress on a given piece of material, and is equal to the product of the proof strain or alteration of figure, into the mean load which acts during the production of that strain: that is to say, in general, very nearly one half of the proof load.

The *Resilience* or *Spring* of a *Beam* is the work performed in bending it to the proof deflection:—in other words, the energy of the greatest shock which the beam can bear without injury: such energy being expressed by the product of a weight into the height from which it must fall to produce the shock in question. This, if the load be concentrated at or near one point, is the product of half the proof load into the proof deflection.—*Rankine.*

The resistance of beams to transverse impact, or a suddenly applied load, is termed their resilience. It is simply proportional to the mass or weight of the beam,

irrespective of the length or the proportion between the depth and breadth.

Thus, if a given beam break with a certain steady load, a similar beam of twice the length will break with half the load applied in the same way; but if the short beam be deflected or broken by a certain falling load, the long beam will require double the load dropped from the same height or the load dropped from twice the height, to produce the same effect.—*Anderson's Strength of Materials.*

The work done in deforming a bar up to the elastic limit is termed the resilience of the bar.—*Unwin.*

162. Timber Trees.

Name.	Mean diam. of trunk.	Average length of trunk.
	in.	ft.
Ash	23	38
Beech	27	44
Chestnut	37	44
Elm	32	44
Riga fir	20	75
Larch	33	45
Mahogany	72	40
Norway spruce ..	15	60
Canadian oak	34	53
English oak	32	42
Sycamore	29	32

—*Law.*

163. Sizes of Fir Timber in Balk.

Stettin	18 to 20 in. square.	
Dantzic	14 „ 16 „	40 to 50 ft. long.
Memel	13 „	35 „
Riga	12 „	40 „
Swedish and Norwegian	8 „ 12 „	

164. Proportions of Beams for Strength and Stiffness, with Minimum Amount of Material.

Strongest	Stiffest
$d : b :: \sqrt{2} : 1$	$d : b :: \sqrt{3} : 1$

Approximately for strength, d to b as 1 to ·7; and for stiffness as 1 to ·58; but 1 to ·5 is often used for beams, where the ends can be fixed sideways, because two can be cut out of a square log, and 1 to ·33 or three out of a square log when intermediate staying can be applied, as in joists.

165. Approximate Proportions of Beams.

Strength.	Stiffness.	Convenience.
ins.	ins.	ins.
12 × 8½	12 × 7	12 × 9 or 12 × 6
10 × 7	10 × 6	10 × 5
9 × 6½	9 × 5¼	9 × 6 or 9 × 4½
8 × 5½	8 × 4¾	8 × 6 or 8 × 4
7 × 5	7 × 4	7 × 4½ or 7 × 2
6 × 4½	6 × 3½	6 × 4
5 × 3½	5 × 3	5 × 3
4 × 3	4 × 2½	4 × 3 or 4 × 2½
3 × 2	3 × 1¾	3 × 2

166. Notes on Torsion and Shafting.

Torsion is measured by the load acting at 1 foot radius, which is required to fracture a specimen 1 inch diameter.

Torsion is similar to shearing, and could be calculated as such, but it is more convenient to take it by leverage as above.

Strength varies as $\frac{d^3}{r}$, stiffness as $\frac{d^4}{l}$.

To run smoothly, long shafting must not twist more than 1° in 10 feet under maximum load.

Long shafts are not designed in strict accordance with rule, as they would then be tapered from driving end, involving extra assortment of driving pulleys.

Every alteration in diameter of a shaft, unless made at a coupling, must be made gradually by means of a curve at the junction of the two diameters, or a long taper.

Factor of safety, long shafts less than $4\frac{1}{2}$ inches diameter $= \frac{1}{10}$; short shafts and all over $4\frac{1}{2}$ inches diameter $= \frac{1}{8}$. Distance apart of supports in feet $= 5 \sqrt[3]{d^2}$. Friction of ordinary shop shafting is about one horse-power per 100 feet.

167. Ultimate Torsional Strength of various Metals.

Round bars 1 inch diameter, load applied at 1 foot radius.

Cast steel,	average	1500	lbs.
Mild steel,	„	1200	„
Wrought iron,	„	800	„
Cast iron,	„	700	„
Wrought copper	„	400	„

These, although average test loads, are rather higher than are usually adopted in practical calculations. See section on calculation of engine shafts.

168. Torsional Modulus of Elasticity.

The torsional modulus of elasticity is about 46 per cent. of the modulus in tension and nearly constant for all classes of material substances.—*Platt and Hayward.*

169. Transmission of Power by Shafting.

Strength of shaft to transmit power depends upon velocity; thus, shaft able to transmit 20 horse-power at

60 revolutions is sufficient for 60 horse-power at 180 revolutions. The explanation is, that the actual strain is the same in each case, the increase in horse-power being due to the increase in speed only. Power consists of pressure and velocity, and varies directly as the amount of each.

170. Formula for Strength of Shafting.

W = B. W. in lbs. at 1 foot radius, of shaft 1 inch diameter.
c = Coefficient of safety.
d = Diameter of shaft in inches.
l = Leverage in feet.
s = Strain in lbs. at circumference of wheel.

$$d = \sqrt[3]{\frac{s\,l}{W\,c}} \qquad s = \frac{W\,d^2}{l} \times c.$$

171. Molesworth's Formula for Wrought-iron Shafting.

D = Diameter of shaft in inches.

$$K = \begin{cases} 320 \text{ for crank shafts and prime movers.} \\ 200 \text{ for second motion shafts.} \\ 100 \text{ for ordinary shafting (but never less than 80).} \end{cases}$$

H = Actual horse-power to be transmitted.
n = Number of revolutions per minute.
l = Leverage in feet.
f = Force applied in lbs. at circumference of wheel.

$$H = \frac{2\,\pi\,l\,n\,f}{33000} \qquad H = \frac{D^3\,n}{K} \qquad f = \frac{D^3}{2\,\pi\,l} \times K.$$

$$f = \frac{33000\,H}{2\,\pi\,l\,n} \quad D = \sqrt[3]{\frac{H}{n} \times K} \quad D = \sqrt{\frac{2\,\pi\,l\,f}{33000} \times K}.$$

172. Proportions of Solid Wrought-iron Flange Coupling on Screw Shaft.

Let d = diameter of shaft. Then there should be eight bolts, each $\frac{1}{4}\,d$ in diameter, the diameter of circle passing through the centres being $1\frac{1}{2}\,d$. The flanges should be $2\,d$ in diameter and $\frac{1}{4}\,d$ thick.—*Unwin.*

Note.—Six bolts are commonly used, up to 6 inches diameter of shaft.

For marine crank shaft, web of throw = $\frac{3}{4}\,d$ thick, pin = d diam., area of bolts (total) = area of shaft.

173. Transverse Strength of Shafts.

Load distributed on wrought-iron crank pin or overhanging journal in lbs., $c = 1200$.
Ditto, concentrated on shaft supported at ends, $c = 2400$.
Ditto, distributed " " " $c = 4800$.

$$\text{Safe load} = c\frac{d^3}{l} \qquad d = \sqrt[3]{\frac{W\,l}{c}}.$$

Forces may be taken to act at the centres of journals in cases where supports are not contiguous to journals.

174. Proportions of Bolts, Nuts, and Washers in Carpentry.

Thickness of nut	=	1	diameter of bolt.
" head	=	$\frac{3}{4}$	" "
Diameter of head or nut over sides	=	$1\frac{5}{8}$	" "
Side of square washer for fir ..	=	$3\frac{1}{2}$	" "
Side of square washer for oak ..	=	$2\frac{1}{2}$	" "
Thickness of washer	=	$\frac{1}{3}$	" "

When the nuts are let in flush in fir, the washers should be same size as for oak.

175. Strength of Bolts.

Bolts in machinery subject to varying loads should not be strained to more than 2 tons per square inch of minimum section. A bolt 1 inch diameter being ·84 at bottom of thread will take not more than (say) 2000 lbs., including initial strain in screwing up.

Let d = outside diameter of thread in inches; $2000\ d^2$ = safe load in lbs. for 1-inch bolts and upwards; $2000\ d^3$ = safe load in lbs. for 1-inch bolts and under.

The ordinary force used in screwing up bolts is liable to break a $\frac{3}{8}$-inch bolt and seriously injure a $\frac{1}{2}$-inch bolt; hence bolts for joints requiring to be tightly screwed up should not be less than $\frac{3}{4}$ inch in diameter.

The approximate area of Whitworth bolts at bottom of thread = diameter of bolt in $\frac{1}{8}$ths inch $\times$ (diameter in $\frac{1}{8}$ths inch $-$ 1) $\div$ 100.

For proportions of Whitworth's Standard see §476.

176. Strength of Bolts (Unwin).

	Per sq. in. net area.
(*a*) Bolts not requiring to be tightened before load is applied also (*c*) when cylinder exceeds 60 inches diameter	Safe load = 6000 lbs.
(*b*) Bolts accurately fitted and requiring to be tightened moderately, also (*c*) when cylinder exceeds 20 inches diameter	„ = 4000 „
(*c*) Bolts used to draw joints steam tight and resist the pressure in addition	„ = 2000 „

177. To Secure Check or Lock Nuts.

Put on check nut ($\frac{1}{2}$ diameter of bolt in thickness), screw up as tight against flange or work as an ordinary nut would be screwed under the circumstances, then put on ordinary thick nut (1 diameter thick), screw it up with the same force and hold on to it with the spanner. Then with a thin spanner reverse the check nut against the other as far as it will go with about the same pressure as before. The check nut has then only the screwing-up force to resist, while the thick nut has in addition the strain which may be brought upon it by load or vibration.

178. Check Nuts.

. . . . This loosening of a nut can be prevented by adding another nut, which must be screwed hard down upon the first, to increase the pressure upon the thread. —*Willis*' '*Mechanism.*'

Note.—As described here, the second nut would only be equivalent to thickening the first nut, and would be useless as a check, unless tightened up to the limits of abrasion.

179. Pressure on Bearing Area in Holes.

The pressure of a pin in an eye, or a bolt in a hole, or a rivet in a plate, resisting a side pull or shearing stress, should be limited to the safe pressure on bearing surface. The maximum pressure (P) per sq. in. assuming the bearing surface to be $\frac{1}{4}$th of the circumference, will be $= P/\cdot 7854\, d\, t$, where $P =$ total pressure, $d =$ diam., $t =$ thickness.

Example :—$1\frac{1}{2}$ in. pin, load 3 tons, thickness $\frac{3}{4}$ in. $p = 3/\cdot 7854 \times 1\cdot 5 \times \cdot 75 = 3\cdot 4$ tons per sq. in. Or if required to limit pressure on bearing area to say 2 tons per sq. in., then $1\frac{1}{2}$ in. pin with 3 tons load will require thickness in eye of $t = 3/\cdot 7854 \times 1\cdot 5 \times 2 = 1\cdot 28$ ins.

SECTION IV.

PATTERN-MAKING, MOULDING, AND FOUNDING.

180. Pattern-making.

Small patterns made of mahogany or New Zealand pine. Larger patterns made of white or yellow pine. Metal patterns used where a great number of similar castings are required. Wood patterns coated with varnish, to prevent distortion from damp sand, black for general body, red for ends of prints or cores, and yellow for machined faces. Some are one colour only.

Patterns should have rounded edges, and filleted angles wherever possible. The thickness of metal throughout a casting should be as uniform as possible, sudden changes of direction being avoided. Sharp angles in a casting are always weak, the crystals while cooling arrange themselves perpendicularly to the surface and hence at a sharp turn there is an awkward junction, which becomes a source of weakness. Sufficient taper must be given to draw out of the sand, and allowance made for knocking to loosen in mould.

181. Black Varnish for Patterns.

Lampblack 1 part, shellac 5 parts, methylated finish 16 parts, all by weight.

182. Allowance for Machining.

Average on iron castings = $\frac{1}{8}$ inch, brass $\frac{1}{16}$ inch. Castings likely to twist in cooling require more, very small castings require less. In small cylinders $\frac{1}{4}$ inch in the diameter is sufficient, cylinders over 4 feet diameter say $\frac{3}{8}$ inch.

183. Moulding in Foundry.

Green-sand Moulding.—Used for light iron castings, firebars, rough machine castings, &c. The ordinary damp sand of the foundry is used in iron boxes or "flasks" for receiving impression from "patterns," the hollow parts being formed of baked sand "cores." Long cores are supported by "chaplets," small and complicated cores are made of "loam."

Dry-sand Moulding.—Used for ornamental ironwork, important machine castings, and for casting in brass. The sand consists of fresh sand mixed with loam which has been used, or of fresh sand only. When finished, the moulds are dried for several hours. "Blackening" prevents sand melting.

Loam Moulding.—Used for steam cylinders, bent pipes, and complicated work. The mould is often built up without patterns, and consists of brickwork coated with loam and "swept" to required shape by a "loam board." Long straight cores are formed of iron pipe with haybands twisted on to hold the loam, and other cores of loam

strengthened by bent "core-irons." The loam is common brick-clay mixed with horse-dung, cow-hair, sand, &c. "Runners" and "gates" are openings in the sand to let the metal into the mould; "vents" are openings to let the gases out, formed by pricking the sand.

184. Sand for Moulding.

Moulding Sand consists of 93 to 96 per cent. of sharp sand and 3 to 6 per cent. of clay. Quality varies for different castings; the smaller the castings, the more clay the sand may contain; heavy castings require poorer and coarser sand. Coal and coke are used to make the sand more porous; this makes the castings rougher, but by giving free vent to the gases makes them sounder. Moulding sand after use is "screened" and wetted before being used again.

Parting Sand is the burnt sand scraped off castings, and is used to facilitate the division of the upper and lower boxes in moulding.

Core Sand consists of 90 per cent. sharp sand and 10 per cent. of clay, and should be used fresh.

185. Foundry Drying Stove.

Brick chamber of three sides with arched top shut with close iron doors on fourth side. Size about 10 feet × 10 feet × 7 feet high. Fire-place on one side, flue near ground on opposite side to spread the heat and carry off the moisture, fire fed through a door on outside. Iron shelves on walls for drying small cores and boxes. Rails run from crane into drying stove, so that large moulds may be wheeled in. Stoves of various sizes in large foundry, the larger ones only used when required for very large moulds.

186. Notes on Moulding and Casting.

Keep most important side of casting at the bottom to ensure density in the metal, as tension flange of girder, &c. Make ample provision for escape of gases by pricking the mould, providing vents, &c. Support long cores and stiffen with core irons to prevent displacement by molten metal. Knock pattern slightly before drawing from mould to enable it to be lifted without breaking the sand. Provide sufficient number of gates to ensure the mould being completely filled with metal. Allow ample head on important castings to cut off all "sullage" or porous and honeycombed portion. The molten metal should be stirred through the gates with an iron rod, called a "feeding rod," to agitate it and cause it to fill angles and corners, more metal being added if required. Directly the metal is run into the mould the gases should be fired to prevent explosion. Metal usually run in afternoon, allowing all night for castings to cool.

187. Cleaning Castings.

Moulds taken apart and sand removed as soon as castings have set, castings taken out with tongs and left to cool, time varying according to weight and mass. Gates, or "gits," and partings, or "fins," broken off, and heavy or hard cores removed in foundry before casting is cold. Projections removed in cleaning or fettling shop with chisel, sharp hammer, or worn-out file, and casting well brushed with steel wire brush. Grindstones or emery wheels used in some shops instead of chisel and file. Holes stopped with black putty, cement, or lead, and castings painted with black wash. The scrap averages 25 per cent. of the castings, less on large work.

188. Classification of Iron Ores.

Mr. Truran classifies the ores of Great Britain into four great divisions, thus:—

A. The argillaceous ores of the coal formations, having clay, but sometimes silica, as the chief impurity.

B. The carbonaceous ores of the coal formations, distinguished by their large percentage of carbon.

C. The calcareous or spathic ores, or the sparry carbonates of iron, having lime as their chief earthy admixture.

D. The siliceous ores, having silica as their predominating earth. This class is subdivided into the red and brown hæmatites, the ores of the oolitic formation, the white carbonates, and the magnetic oxides.

189. Charges employed at Dowlais for different kinds of Pig-Iron.

	Foundry Pig.	White Forge Pig.	Common Forge Pig.
	cwt.	cwt.	cwt.
Calcined "mine" (fresh ore)	48	28	..
Red hæmatite ore	..	10	16
Forge and refinery cinder ..	..	10	25
Limestone	17	14	16
Coal	50	42	36
Weekly make	130 tons.	170 tons.	190 tons.

190. Analyses of Pig-Iron.

	Per cent.
Carbon, partly combined, and partly in a graphitic form	2·3 to 5·5
Silicon	0·13 „ 5·7
Manganese	0·0 „ 7·6
Sulphur	0·0 „ 0·87
Phosphorus	0·0 „ 1·66

191. Foundry Pig.

No. 1 Pig is chiefly used in the foundry. Colour dark grey, crystals large and leafy, carbon in form of graphite. Very soft, melts very fluid, but being coarse grained, will not give a sharp impression. Cools slowly. For fine castings the presence of a little phosphorus is advantageous: the grain is finer, the iron a lighter colour, and the impressions sharper. Used for small castings, hollow ware, small machinery, &c.

No. 2 Pig, grey and mottled in colour. Used for large castings in dry sand or loam. Melts fluid, is tough, close texture, fills the mould well, more free from impurities than No. 1. Heavy machine castings made from No. 2, or various mixtures of 1, 2, and 3.

No. 3 Pig, hard and white, used for mixing.

192. Mixtures of Pig-Iron.

Mixture recommended for girders, &c., where rigidity and strength are required:—

Lowmoor, Yorkshire No, 3	30 per cent.
Blaina or Yorkshire No. 2	25 „
Shropshire or Derbyshire No. 3 ..	25 „
Good old cast scrap	20 „
	100

—*Fairbairn.*

Mixture for steam cylinders, strong and close grained.

No. 5 Charcoal Pig	8 parts.
Scotch Pig	10 „
Good cast scrap	10 „

For the same, where greater hardness is required.

No. 5 Charcoal Pig	.. ..	2 parts
Scotch Pig	.. ..	4 „
Good cast scrap	.. .. ..	30 „

Piston rings should be of softer metal than the cylinders. —*Rigg's 'Steam Engine.'*

193. Melting Metal for Castings.

Crucibles are sometimes used for melting iron for trinkets and small goods. The best castings, whether iron, bronze, or other metal, for machine frames, bells, statues, &c., are made from a *reverberatory furnace*, run directly from the furnace in dry sand ditches to the mould. The *cupola* has the advantage of melting iron cheaper than any other furnace; where strength is unimportant, it is the best method.

194. Contraction of Metals in Cooling.

Metal.	Contraction. In Fractions of Linear Dimensions.	Contraction. In Parts of an Inch per Foot of Linear Dimensions.
Cast iron	$\frac{1}{96}$	$\frac{1}{8}$
Gun metal	$\frac{1}{72}$	$\frac{1}{6}$
Yellow brass	$\frac{1}{64}$	$\frac{3}{16}$
Copper	$\frac{1}{60}$	$\frac{1}{5}$
Zinc and Tin	$\frac{1}{48}$	$\frac{1}{4}$
Lead	$\frac{1}{39}$	$\frac{5}{16}$

195. Contraction of Castings.

Heavy pipes	.. .. .. =	$\frac{1}{8}$	inch per foot.
Girders, beams, &c.	.. .. =	$\frac{1}{8}$	„ in 14 inches.

Engine beams, Connecting rods	=	$\frac{1}{8}$ inch in 16 inches.
Large cylinders, say 70 inches diameter × 10 feet stroke, the contraction of diameter ..	=	$\frac{3}{8}$ " at top.
	=	$\frac{1}{2}$ " at bottom.
Ditto in length	=	$\frac{1}{8}$ " in 16 inches.
Small narrow wheels, about	=	$\frac{1}{25}$ " per foot diam.
Large heavy wheels	=	$\frac{1}{10}$ " or more "
Thin brass	=	$\frac{1}{8}$ " in 9 inches.
Thick brass	=	$\frac{1}{8}$ " in 10 inches.
Gun-metal rods	=	$\frac{1}{8}$ " in 9 inches.
Zinc	=	$\frac{5}{16}$ inch per foot.
Copper	=	$\frac{3}{16}$ " "
Bismuth	=	$\frac{5}{32}$ " "
Tin and lead, each	=	$\frac{1}{4}$ " "

Pattern-makers commonly allow for iron castings $\frac{1}{8}$ inch per foot, and for brass castings $\frac{3}{16}$ inch per foot. The apparent contraction varies considerably according to the amount of "rapping" the pattern receives in the sand.

196. Bronze and Brass Castings.

Melted in crucibles, wasting prevented by covering surface with mixture of potash, soda, and charcoal powder. Copper melted first, then tin, zinc, or antimony, then covering applied. Zinc is best added in form of brass, calculating the copper contained. Large strong castings require the metal exposed to fire in fluid state 8 or 10 hours, proof taken by small ladle and broken when cool, judged by crystallisation, and copper or tin added as required. Before casting, bronze is well stirred with heated iron rods. Brass made by melting together copper

scraps, crude zinc or spelter, and charcoal powder, remelted for casting. About 7 lbs. per cwt. is allowed for waste.

SECTION V.

FORGING, WELDING, RIVETING, Etc.

197. Forging.

Wrought iron at a red heat may be hammered into various shapes, called "forging." When a piece is drawn down smaller it is called "swaging"; if jumped up thicker, it is called "upsetting." Common iron is not suitable for forging, as the scale or slag in it causes cracks. Double and treble best Staffordshire and ordinary Yorkshire are suitable. The best Yorkshire is used for flanging and difficult forgings. Charcoal iron for light and complicated work.

Steel may be forged gradually at a low heat. The greater the proportion of carbon contained, the greater the difficulty of forging. All forging should proceed by easy stages, and care be taken not to burn the iron or steel. Large pieces have a rod or "porter" welded to them for convenience in handling by a crane.

198. Welding

Is the process of joining two pieces of wrought iron or steel by heating, and hammering them together. To weld iron the pieces must be brought to a white heat, and the scale swept off before they are put together. Steel requires a much lower heat, and the surfaces should be sprinkled

with sand, borax, or silicate of soda, to aid the surface fusion. Borate of soda similarly aids the surface fusion of spelter in hard soldering. The welding temperature depends upon the amount of carbon contained: hence, the extra difficulty of welding two pieces of different composition. Mild steel approaches wrought iron in its welding qualities. Steel faces may with care be welded on to iron tools; shear steel is generally used for this purpose. Average loss of strength in weld is 15 to 20 per cent.

In electric welding, a current is passed through the abutting edges which are pressed together, surface-fusion is almost immediately produced, and the junction commences at the centre, proceeding uniformly to the outside. This weld is said to be of equal strength with the solid material, but the loss probably reaches 10 per cent.

199. Tempering.

Steel when heated to a cherry red, and suddenly cooled in water or oil, is rendered very hard. Some suppose that the carbon is caused to take the crystalline or diamond form. For tempering the hardened steel a portion is brightened with a piece of broken grindstone, and then reheated until the film of oxide formed on the surface shows the requisite temperature; it is then quenched in water, and the hardness is found to be "let down" to the "temper" required. Tempering was formerly considered to be the only true test of steel.

200. Colours corresponding to Temperature.

	Deg. Fahr.
Lowest red heat visible in the dark ..	635
Faint red	960
Dull red	1290

	Deg. Fahr.
Brilliant red	1470
Cherry red	1650
Bright cherry red	1830
Orange	2010
Bright orange	2190
White heat	2370
Bright white heat	2550
Dazzling white heat	2730
Welding or scintillating heat	2800

—*Becquerel, Pouillet, &c.*

201 (see next page).

202. Notes on Riveted Joints.

Hard wrought iron is weakened from 15 to 30 per cent. by punching. In punched plates the small sides of the holes should come together. Drilled holes should have the edges chamfered.

The tension in a rivet may be estimated at 21,000 lbs. per square inch of its section. Friction due to this tension would be about 7000 lbs. per square inch of rivet section.

The usual diameter of rivets in hand riveting varies from $\frac{1}{2}$ inch to $\frac{7}{8}$ inch. In machine riveting they may be used up to $1\frac{1}{4}$ inch diameter.

Maximum efficiency of single riveted joint = $\frac{2}{3}$ strength of plate. Ordinary efficiency = $\frac{9}{16}$. Maximum efficiency of double riveted joint = $\frac{4}{5}$ strength of plate. Ordinary efficiency = $\frac{3}{4}$.

Pitch of rivets (for equal area of plate and rivet) =

$$\frac{\text{Sect. area of rivet} \times \text{effective No. of rows}}{\text{Thickness of plate}} + \text{diam. of rivet.}$$

$$\text{Chain riveting} = \begin{matrix} \times & \times & \times & \times \\ \times & \times & \times & \times \end{matrix}.$$

$$\text{Zigzag, reeled, or staggered} = \begin{matrix} \times & & \times & & \times & \\ & \times & & \times & & \times \end{matrix}.$$

201. Tempering Steel.

Colours produced at various Temperatures, and Alloys fusible at same.

Colour of film.	Temp. Fahr.	Nature of Tool.	Lead.	Tin.
None	400°	.. .. ..	22	16
Very pale yellow straw	430	Lancets and turning-tools for metal	30	16
A shade of darker yellow	450	Razors and ditto	34	16
Darker straw yellow	470	Penknives	42	16
Orange yellow	490	Cold chisels, drills, screw taps, wood tools	56	16
Brownish yellow	500	Hatchets, plane-irons, chipping-chisels, saws for	66	16
Yellow tinged with purple ..	520	iron, tools for working granite	100	16
Light purple	530	Swords, ordinary springs, tools for cutting sand-	120	16
Dark purple	550	stone	192	16
Dark blue	570	Small saws, watch-springs	..	..
Pale blue	600	Large saws, pit and hand saws	..	..
Pale blue with tinge of green ..	620	Too soft for steel instruments	All	0
Grey	750			

To rivet by hand requires a minimum of 1 diameter, and by machine $1\frac{1}{8}$ diameter of rivet to form head. Length of rivet for good head = thickness of plates passed through + $1\frac{1}{2}$ diameter + $\frac{1}{16}$ inch for each joint. Rivets 6 to 8 diameters long often draw off their heads. Rivets are usually $\frac{1}{16}$ inch smaller than hole, generally $\frac{3}{4}$ inch iron in $\frac{13}{16}$ inch hole, but may be $\frac{11}{16}$ inch iron in $\frac{3}{4}$ inch hole. Countersunk rivets 60°, countersunk $\frac{2}{3}$ diameter of rivet.

A rivet hole cannot be punched with its edge nearer the edge of the plate than its own diameter without risk of its bursting through. To this it is safe to add $\frac{1}{8}$ inch to $\frac{1}{4}$ inch on the plate as the size of rivet and thickness of plate increase. The edges of two holes cannot be nearer than 1 to $1\frac{1}{2}$ diameter without risk of the second hole distorting the first, or the two holes punching into one.

The efficiency of the bearing surface of rivets = 5 tons per square inch; thus a $\frac{7}{8}$ inch rivet in a $\frac{3}{4}$ inch plate = $\frac{7}{8} \times \frac{3}{4} \times 5 = 3 \cdot 3$ tons nearly.

18 rivets go to the "yard" for piece work, irrespective of the pitch.

In hydraulic riveting the pressure on the cup head = 12,000 to 16,000 lbs. per square inch of surface.

203. Proportion of Rivet Diameter to Thickness of Plate.

In punching, the resistance of steel = 100[k.] per sq. cm.
 „ „ iron = 30 „ „

Punch = $100 \times \frac{\pi d^2}{4}$, plate = $30\,\pi d \times e$.

$$\therefore\ d > \frac{30\,\pi\,d\,e}{100\,\frac{\pi d}{4}} = 1 \cdot 2\,e \ (e = \text{thickness}),$$

but d must be $< 3\,e$ or crushing by the pressure of the

rivet on edge of plate will occur, hence the usual proportion of $d = 2e$. —*Planat.*

204. Riveting.

Heads $\cdot 66\,d \times 1\cdot 66\,d$ with radius of $\cdot 86\,d$. Length to make this $= 1\,d$ (?), N = tension, ω = section, t = temperature of heated rivet when closed, E = coefficient of elasticity, then

$$\frac{N}{\omega} = \frac{7\,E\,t}{11 \times 81{,}500},$$

N being the tension capable of producing a stretch equal to that by temperature t.

The tension is independent of the length, and varies solely as the closing temperature, which should not exceed 212° F. Adhesion due to this temperature $= 9 \cdot 4^{k.}$ per sq. mm. and at 150° C. $= 14^{k}$. —*Planat.*

205. Notes on Caulking.

Caulking consists of burring up the inner edge of the plates in a joint by means of a tool like a flat-ended chisel, to prevent leakage in boilers, tanks, &c.

Plates with rough sheared edges should be chipped even, to a slight bevel, before caulking.

Joints appearing at all open should be closed by a flogging hammer before caulking.

When the caulking is done on one side only, it should be upon the same side as the riveting. In best work the joints are caulked inside and out.

When the lap exceeds three times diameter of rivet the caulking is apt to open the joint, unless done very lightly.

206. Caulking Tools.

The caulking tool should be flat-ended and slightly bevelled, from $\frac{1}{8}$ inch to $\frac{3}{16}$ inch thick $\times$ 1 inch to $1\frac{1}{4}$ inch wide, with one edge square and the other rounded to prevent cutting into the plate.

The rounded edge should be held next to the plate the first time of going along the joint, called splitting the lap, and afterwards reversed.

The finished caulking should appear like a parallel groove about $\frac{1}{32}$ inch deep $\times$ $\frac{1}{8}$ inch wide in a $\frac{3}{8}$-inch plate.

SECTION VI.

WORKSHOP TOOLS AND GENERAL MACHINERY.

207. Object of Machines.

The object of machines is to change the direction of motion, or to regulate the distribution of power. They transmit energy and modify it in direction, intensity, or velocity, but they can neither create nor increase power. An *engine* transmitting energy from *natural forces* is called *a prime mover*, but is otherwise a machine.

The POWER of a machine is measured by the WORK which can be done in a given TIME.

208. Machines are used for—

1. Accumulating force upon a given point or object.
2. Increasing or decreasing velocity of motion.
3. Prolonging the action of a power.

4. Changing the direction of motion.
5. Reducing the time of labour.
6. Producing accuracy in work.

THE PARTS MAY BE DIVIDED INTO—

1. Receivers.
2. Communicators.
3. Operators.

MOTIVE POWER MAY BE DERIVED FROM—

1. Man and animals.
2. Fall of water.
3. Force of wind.
4. Descent of weights.
5. Action of springs.
6. Expansion of elastic fluids.
7. Electricity and magnetism.
8. Chemical reactions.

209. MACHINERY IN MOTION.

In engines or machines in motion, when the power exceeds the work the speed will be accelerated, unless prevented, until the resistance + the useful work = the power. When the resistances + the useful work, exceed the power, the speed will be retarded until a balance is again obtained. In the former case the inertia of the parts will absorb some of the power, and in the latter this power will be again given out as momentum.

Motion may be rectilinear or curvilinear—direct or reciprocating—uniform or variable (uniformly accelerated, uniformly retarded, or irregular).

210. Useful Work and Efficiency.

Useful work of a machine is that performed in producing the effect for which the machine is designed.

Lost work is that performed in producing other effects.

The *power* of a machine is the energy exerted, and the *effect* the useful work performed, in some interval of time of definite length.

The *efficiency* [or *mechanical efficiency*] of a machine is a fraction expressing the ratio of the useful work to the whole work performed or energy expended. This ratio is also called the *modulus* or *coefficient* of the machine.

The *counter-efficiency* is the reciprocal of the efficiency, and is the ratio in which the energy expended is greater than the useful work.—*Rankine's 'Applied Mechanics.'*

211. Economical Working of Machines.

In every machine a certain rate of work develops the maximum efficiency. A medium load with a fair velocity produces more units of work than a heavier load with a less velocity, or a lighter load with a greater velocity.

212. Velocity Ratio.

The *velocity ratio* in any machine is the proportion between the movement of the power and the movement of the resistance, in the same interval of time; for example, in a punching press it may be 100 to 1 = $\frac{100}{1}$, and in a hydraulic crane 1 to 8 = $\frac{1}{8}$. These proportions also express the amount of the resistance (including friction), compared with the power or pressure applied. (See also the definitions of *virtual velocity*, § 214.)

The term *purchase* of a machine is applied either to the

motion or pressure of the resistance compared with the power; in above examples, the purchase of the punching press would be 100, that of the hydraulic crane 8, but the term is generally restricted to the gaining of pressure by the sacrifice of speed, as in the first case.

By the *mechanical advantage* of any machine is meant the ratio of the weight (or resistance) to the power, when in equilibrium. Sometimes improperly called the mechanical efficiency.

213. Principle of Virtual Velocities.

If any machine without friction be in equilibrium and the whole be put in motion, the initial pressure P will be to the final pressure p as the final velocity V is to the initial velocity v, or $P : p :: V : v$, or $p\,V = P\,v$.

In practice, as all machines have friction, p will depend upon the friction, but V will be in accordance with the calculation of the leverage or gearing.

Let $e =$ the final pressure by experiment, then $p - e$ = friction, and the coefficient or modulus of machine $M = \frac{e}{p}$.

214. Definitions of the Principle of Virtual Velocities.

Rankine's.—The effort and resistance are to each other inversely as the velocities, along their lines of action, of the points where they are applied.

Twisden's.—If a system of pressures, in equilibrium, act on any machine which receives any small displacement, consistent with the connection of the parts of the machine, the algebraical sum of the virtual moments of the pressure will equal zero.

215. Angular Velocity.

The angular velocity of a wheel is the speed of a point in the circumference of an imaginary wheel with unity as radius, and making the same number of revolutions per minute as the given wheel.

Velocity is taken in feet per second.
Revolutions are taken at per minute.

$$\text{Circumferential velocity} = \frac{2\,\pi\, r\, n}{60} = \frac{\pi\, r\, n}{30} = \cdot 10472\, r\, n.$$

$$\text{Angular velocity} = \frac{2\,\pi\,(r)\,n}{60} = \frac{\pi\, n}{30} = \cdot 10472\, n.$$

$$\frac{\text{V. of any point in wheel}}{\text{rad. of ditto in feet}} = \text{angular velocity.}$$

216. Angular Measurement of Forces.

A *radian*, or unit of angular rotation, is an arc of a length equal to radius, it contains $57 \cdot 2958$ degrees $= \frac{180^\circ}{\pi}$. A right angle therefore contains $1 \cdot 5708$ radians, two right angles $3 \cdot 1416$ radians, and four right angles $6 \cdot 2832$ radians; or one revolution $= 2\,\pi$ radians, and

$$n \text{ revolutions per minute} = \frac{2\,\pi\, n}{60} \text{ radians per second.}$$

$$\frac{\text{degrees in an angle}}{57 \cdot 2958} = \text{No. of radians}$$

$$\text{radius} \times \text{No. of radians} = \text{length of arc.}$$

The angular velocity of a wheel may be measured in radians per second.

A *round* is the angular space traversed in one revolution.

A round contains 6·2832 radians. The linear velocity of a point in a wheel is equal to the angular velocity × the distance in feet of the point from the axis. All points in a revolving wheel have the same angular velocity.

A *torque* (Jas. Thomson) is a system of forces, not meeting in one point, which, acting upon a body, may be parallel to and proportional to the sides of a closed polygon, but whose turning moments do not balance about any axis. It is equivalent to a "couple." In machinery it means turning moment or turning force × distance from centre of shaft.

In Ayrton and Perry's dynamometer coupling, or transmission dynamometer, the total amount of the forces of the springs in pound-feet, or the "torque," × angular velocity per minute ÷ 33000 = the horse-power, thus:

$$\text{H.P.} = \frac{\text{torque} \times \text{angular } v. \text{ per minute}}{33{,}000}.$$

217. Angle of Twist.

A straight line drawn along a shaft not transmitting power, becomes a spiral while power is being transmitted. The angle between the spiral line at any point and the original direction divided by the radius of the shaft is called the angle of twist.—*Perry.*

218. Workshop Tools.

Are divided into two classes, hand tools and machine tools. In the former are included hammers, chisels, files, ratchet braces, spanners, &c., and in the latter lathes, planing, shaping, drilling, and slotting machines, &c., in the fitting shop; and punching and shearing machines, bending rolls, steam hammers, &c., in the smiths' shop.

The machine tools are now mostly driven by steam power through shafting connected by belts.

A workshop should be so arranged that the raw material coming in at one end would be received at the various tools in the order of the work to be done upon it, and be removed in a finished state at the other end.

219. Hammers.

Name.	Weight.	Length of shaft.
	lbs.	in.
Sledge	28, 24, 18 and 14	40
Flogging	7 and 5	30
Riveting	4 and 3	24
Hand	2	20
Fitting	$1\frac{3}{4}$	16
Bench	$1\frac{1}{2}$	14
"	1	12

220. Work of Hammer.

Hammer 2 lbs., velocity 20 ft. per second, drives nail $\frac{1}{2}$ in. into hard wood; required the equivalent dead pressure? (v. after striking = 20 to 0, mean = 10, $\therefore$ t in driving $\frac{1}{2}$ in. $= \frac{1}{240}$ of a second.)

$$\text{1st by} \quad F = \frac{W\,v}{g\,t}, \quad \frac{2}{32\cdot 2} \times \frac{20}{\frac{1}{240}} = 298 \text{ lbs.}$$

$$\text{2nd by} \quad \frac{W\,v^2}{2\,g}, \quad \frac{2}{32\cdot 2} \times \frac{20^2}{2} = 12\cdot 42 \text{ ft. lbs. and } \frac{12\cdot 42}{\frac{1}{24}}$$

$$= 298 \text{ lbs. as before;}$$

but this will only be the *mean* pressure. From experiments it appears that the maximum pressure required is about $1\frac{3}{4}$ times mean pressure, so that the actual dead

pressure required to force same nail same depth would be $298 \times 1 \cdot 75 = 521 \cdot 5$ lbs., and the force required to extract it, being about $\frac{4}{5}$ of pressure to insert it, would be $521 \cdot 5 \times \frac{4}{5} = 417$ lbs. Where the resistance varies simply as the depth driven the maximum pressure is double the mean. The same principles apply to pile driving. See leaflet by the author on 'The Force of Hammers; or, Percussion *v.* Pressure.'

221. Impact of Moving Bodies.

In these formulæ mass may be substituted for weight without affecting the result.

W = weight	of body	A	giving	blow.	
V = velocity	,,	A	,,	,,	
V^1 = ,,	,,	A	,,	,,	after impact.
w = weight	,,	B	receiving	blow.	
v = velocity	,,	B	,,	,,	
v^1 = ,,	,,	B	,,	,,	,,

BODIES PERFECTLY SOFT OR INELASTIC.	BODIES PERFECTLY ELASTIC.

(1) Both moving in same direction.

Inelastic	Elastic
$V^1 = v^1 = \dfrac{W V + w v}{W + w}.$	$V^1 = 2 \dfrac{W V + w v}{W + w} - V.$ $v^1 = 2 \dfrac{W V + w v}{W + w} - v.$

(2) *A* moving, *B* at rest.

Inelastic	Elastic
$V^1 = v^1 = \dfrac{W V}{W + w}.$	$V^1 = 2 \dfrac{W V}{W + w} - V.$ $v^1 = 2 \dfrac{W V}{W + w}.$

(3) Both moving in opposite directions.

$$V^1 = v^1 = \frac{W V - w v}{W + w}.$$

$$V^1 = 2\,\frac{W V - w v}{W + w} - V.$$

$$v^1 = 2\,\frac{W V - w v}{W + w} - v.$$

Resulting motion towards A if result $-$.

" " " B " $+$

Or putting R = mutual action between two bodies moving in opposite directions.

$$R = \frac{W w (V + v)}{W + w}.$$

$$V^1 = \frac{w v - R}{w}.$$

$$v^1 = \frac{W V - R}{W}.$$

$$V^1 = \frac{w v - 2 R}{w}.$$

$$v^1 = \frac{W V - 2 R}{W}.$$

For intermediate condition of matter, between perfectly soft and perfectly elastic, use coefficient $e\,R$.

Example of Case 2.

Body A weighing $W = 10$ lbs. moving at velocity $V =$ 20 ft. per second, strikes body B weighing $w = 30$ lbs. at rest. When perfectly soft or inelastic $\frac{W V}{W + w} = \frac{10 \times 20}{10 + 30}$ $= 5$ ft. per second as the resulting velocity of A and B moving together. But, by formula for kinetic energy, if the units of work existing in A remain in the combined masses after striking, $\frac{W V^2}{2 g} = \frac{(W + w) V_1{}^2}{2 g}$, the

resulting velocity would appear to be $V_1 = V\sqrt{\frac{W}{W+w}}$ $=20\sqrt{\frac{10}{10+30}} = 10$ ft. per sec.

The explanation is that the total *momentum* is always the same but the *energy* is only constant when the bodies are perfectly elastic, i.e. when the restitution is complete. When the elasticity is imperfect part of the *work* is used in compressing the particles, and the lost velocity is transformed into *heat.*

If the same bodies were perfectly elastic the resulting velocity of A would be

$$V^1 = 2\frac{W\,V}{W+w} - V = 2\left(\frac{10 \times 20}{10+30}\right) - 20 = -10 \text{ ft. per sec.}$$

i.e. it would rebound at half the striking velocity, and the resulting velocity of B would be

$$v^1 = 2\frac{W\,V}{W+w} = 2\left(\frac{10 \times 20}{10+30}\right) = 10 \text{ ft. per sec. in forward}$$

direction.

The energy before and after would be $\frac{W\,V^2}{2g} = \frac{W\,V_1^2}{2g} + \frac{w\,v_1^2}{2g}$, $10 \times 20^2 = (10 \times -10^2) + (30 \times 10^2)$, or $4000 = 1000 + 3000$. Q. E. D.

222. Notes on Workshop Tools and Fittings.

Top of vice jaws from floor = 40 in. to 44 in., say average of 42 in., or level with the elbow.

223. Holtzapffel's Classification of Cutting Tools.

Shearing tools act by dividing the material operated on into two parts, which separate from each other by sliding at the surface of separation.

Paring tools cut a thin layer or strip called a shaving from the surface of the work, and thus produce a new surface.

Scraping tools scrape away small particles from the surface of the work, thus correcting the small irregularities which may have been left by the paring tool.

224. Angles of Tools.

	Angle of Tool.
For wood	30° to 40°
„ wrought iron	60°
„ cast iron	70°
„ brass	80°

Angle of relief for all tools, 3° to 10°.

225. Cutting Speed of Machine Tools.

	Ft. per Min.	
Cast steel ..	10 to 12	
Mild „	12 „ 15	
Cast iron	15 „ 20	
Wrought iron ..	15 „ 25	
Gun metal ..	20 „ 40	
Yellow brass ..	40 „ 60	
Wood	500 „ 2000	when material revolves.
„	3000 „ 5000	when tool revolves
Grindstone ..	800 „	
Milling wrot. iron	80 „ 100	
„ cast steel	25 „ 30	

Average for wrought or cast iron in lathe, shaping slotting, &c., 20 ft. per min.

226. Average Cutting Speeds and Feeds.

Material.	Roughing.		Finishing.	
	Speed ft. per min.	Feed. cuts per min.	Speed. ft. per min.	Feed. cuts per min.
Wrought Iron	25	20	25	25
Steel	18	25	15	30
Cast Iron	25	16	25	6

227. Speed of Machine Tools.

Speed of cut { Wrought iron, 20 feet per minute.
Cast iron, 16 „ „
Cuts per inch, 16 to 80.

For flat work—

Speed in inches per second × 5 = speed in feet per minute.

For small diameters—

Diameter in inches × revolutions in 16 seconds = speed in feet per minute.

For large diameters—

$$\frac{\text{Diam. in inches} \times 16}{\text{Seconds for 1 revolution}} = \text{speed in ft. per min.}$$

$$\frac{\text{Cutting speed in feet per min.} \times 5}{\text{Cuts per inch}} = \text{sq. ft. tooled per hour.}$$

—'*Engineering.*'

228. Cutting Speeds.

Shearing and punching	2	feet per minute.
Turning malleable cast iron ..	3	" "
Screwing	6	" "
Turning steel	10	" "
Do. cast iron	16	" "
Do. wrought iron	21	" "
Do. bronze	30	" "

—'*English Mechanic.*'

229. Speed in Cutting Metals.

Turning chilled rolls	3 to 4	ft. per min.
Screw-cutting steel in lathe	7½	" "
Turning and planing steel	10	" "
Boring cast iron cylinders	12	" "
Turning planing and shaping cast iron	15 to 20	" "
Do. do. wrot. iron and very soft cast iron	20 " 40	" "
Do. do. steel	24 " 30	" "
Do. do. brass	36 "100	" "
Screw-cutting gun metal	30	" "
Turning copper	30	" "
Bandsaws for hot iron and steel ..	200 to 300	" "
Circular saws for do. do.	12,000 to 27,600	" "

—*Keerayeff.*

Circular saw, consisting of soft iron disc running at circumferential speed of 12,000 feet per minute, is used for cutting ends of steel rails, with jet of water playing on circumference of saw.

230. Resistances in Machine Tools.

TWIST DRILL.

Pressure on head of twist drill in lbs. requisite to produce proper cut = diameter of drill in inches and decimals × 1500.

LATHE.

Material.	Width of cut.	Depth of cut.	Speed of cut.	Resistance to traverse of tool.
	in.	in.	ft. per min.	lbs.
Steel	$\frac{1}{20}$	$\frac{1}{20}$	5	600
Wrought iron	$\frac{1}{20}$	$\frac{1}{10}$	10	700
Cast iron	$\frac{1}{20}$	$\frac{1}{16}$	15	325

PLANING MACHINE.

Cast iron, width of cut $\frac{1}{16}$ in., speed of cut 11 ft. per min. With depth of cut = $\frac{1}{32}$ in. pressure against tool varied from 356 to 396 lbs. averaging 373 lbs. or 4065 ft. lbs. work per min. With depth = $\frac{1}{16}$ in, pressure varied from 340 to 559 lbs., averaging 458 lbs. or 5000 ft. lbs. work per min.

Milling Cutters Made from "Böhler" Steel.

Diameter of cutter	36 mm.
Revolutions per minute ..	110
Travel per minute	32 mm.
Feed	5 „
Length of cut	80 „
Weight of steel cut per hour ..	6 kilos.

The above results have been obtained by work on pieces of middling hard steel, that is to say, a steel equal to a resistance of 55 to 60 kilos. per mm.; the average time occupied has been 5 hours, without showing any deterioration to the tool.

231. Screw Cutting.

Set of change wheels numbers 22; increasing by 5 teeth from 20 to 120, two being alike, generally 80 or 90. When 25 in a set, the extra wheels are 130, 140, and 150.

Wheels of 10 and 15 teeth are supplied when the screw-cutting gear works the slide rest.

Leading screw has usually 2, 3, or 4 threads per inch.

Double train must always be used when $\dfrac{\text{leading screw}}{\text{screw required}}$ is less than $\frac{1}{6}$, generally when less than $\frac{1}{4}$.

When the number of threads per inch required to be cut can be divided without remainder by the number of threads per inch in the leading screw, the clamping nut under the saddle will drop into gear with the leading screw without chalking.

Always retain the mandrel wheel for a screw-cutting train when possible.

TO FIND THE WHEELS FOR ANY PITCH.

Single train—

$$\frac{\text{Threads per inch in leading screw}}{\text{,, \quad ,, \quad screw to be cut}} = \frac{\text{driver}}{\text{follower}}.$$

Double train—

$$\frac{\text{Threads leading screw}}{\text{Threads screw required}} = \frac{\text{driver}}{\text{follower}} \times \frac{\text{driver}}{\text{follower}}.$$

EXAMPLES OF CHANGE WHEELS.

Single trains—

Leading screw, 4 threads; Required ,, 7 ,,
$$\frac{4}{7} \times \frac{5}{5} = \frac{\mathbf{20}}{\mathbf{35}}, \text{ or } \times \frac{15}{15} = \frac{\mathbf{60}}{\mathbf{105}}$$

Leading ,, 4 ,,; Required ,, $2\frac{3}{4}$,,
$$\frac{4}{2\frac{3}{4}} = \frac{16}{11} \times \frac{10}{10} = \frac{160}{110} \div \frac{2}{2} = \frac{\mathbf{80}}{\mathbf{55}}$$

Leading ,, 4 ,,; Required ,, ·75 ,,
$$\frac{\cdot 75 \times 100 \times 4}{100} = \frac{300}{100} = \frac{30}{10} \times \frac{4}{4} = \frac{\mathbf{120}}{\mathbf{40}}.$$

Double trains—

Leading screw, 4 threads Required „ $\frac{5}{8}$ pitch	$\dfrac{5\times 4}{8} = \dfrac{5\times 4}{2\times 4} = \dfrac{50\times 40}{20\times 40} = \dfrac{\mathbf{50\times 80}}{\mathbf{20\times 80}}$
Leading „ 4 threads Required „ 100 „	$\dfrac{4}{100} = \dfrac{2\times 2}{5\times 20} = \dfrac{20\times 20}{50\times 200} = \dfrac{\mathbf{20\times 10}}{\mathbf{50\times 100}}$
Leading „ 4 „ Required „ ·08 „	$\dfrac{4\times \cdot 08\times 100}{100} = \dfrac{4\times 8}{10\times 10} = \dfrac{40\times 80}{100\times 100} = \dfrac{\mathbf{20\times 80}}{\mathbf{50\times 100}}.$

Trains to be used are shown in broad-faced type.

232. Screw for Worm Wheel.

To find change wheels to cut screw,

D = diametral pitch of worm wheel.
d = diameter of worm wheel at pitch circle.
n = number of threads per inch in leading screw.
t = number of teeth in wheel.

$$\frac{\pi n}{D} = \frac{22\,n}{7\,D} = \frac{Driver}{Follower},$$

$$\frac{\pi d n}{t} = \frac{22\,d n}{7\,t} = \frac{Driver}{Follower}.$$

To cut double, treble, or more threads or worms:—

Find the smallest set of wheels that will cut the required pitch single thread, then multiply the drivers by the number of threads required.

233. Velocity of Wood-working Machinery.

Saw frame (several saws)	8 ft. per second.
Do. (one saw)	10 to 15 „ „
Band saw	40 to 50 „ „
Turning wood	15 to 40 „ „

Revolving cutters	.. 60 to 100 per second.	
Circular saw (across grain) ..	.. 80 to 100 „	„
Do. (with grain) ..	100 to 130 „	„

—*Keerayeff.*

To saw green oak lengthways requires 29,000 ft. lbs. work per ft. sup.

234. Speed of Polishing and Grinding.

Tool grindstone	400 to 900 ft. per minute.	
Polishing by emery and oil ..	.. 750 „	„
Do. by grindstone ..	.. 2000 „	„
Do. by dry emery wheel	3000 to 4000 „	„

—*Keerayeff.*

235. Rolling Mill Speeds.

Velocity of rolls in feet per second.

Squeezing	3
Plates	4 to $6\frac{1}{2}$
Rails, angles, and tees	$5\frac{1}{2}$
Rods and bars	6 to 8
Fly wheels for mill	80 to 100
Wire drawing rollers	1 to $3\frac{1}{4}$
Cold rolling	$\frac{1}{3}$
Plate bending	$\frac{1}{16}$

—*Keerayeff.*

236. Shearing and Punching.

Resistance to shearing of wrought iron averages 50,000 lbs. per square inch area of surface cut. This will be the pressure required on the material at the commencement of the stroke.

The mechanical work in punching or shearing is estimated by Weisbach as this pressure exerted through $\frac{1}{6}$th the thickness of the plate, and the coefficient or modulus of the machine as ·66, the friction being taken at 33 per cent. of the gross pressure.

For rectangular bars the pressure may be taken as exerted through $\frac{1}{4}$th the thickness, and for round bars $\frac{1}{3}$rd the diameter.

Formula for calculating power required:

t = Thickness of plate or bar.
l = Length or circumference of cut.
f = Resistance of material to shearing.
M = Modulus of machine, say ·66.
P = Gross pressure in lbs.

$$P = \frac{t\,l\,f}{M}.$$

Pressure required to punch wrought-iron plates. (From experiments).

	d.		*t.*		*P.*		*c.*
To punch	$\frac{1}{8}$	hole in	$\frac{1}{8}$	plate requires	$2\frac{1}{4}$	tons =	144
Do.	$\frac{1}{4}$	,,	$\frac{1}{4}$	,,	$6\frac{1}{2}$	,,	104
Do.	$\frac{3}{8}$	,,	$\frac{3}{8}$	,,	13	,,	92
Do.	$\frac{1}{2}$	,,	$\frac{1}{2}$	,,	22	,,	88
Do.	$\frac{5}{8}$	,,	$\frac{5}{8}$	,,	$33\frac{1}{2}$	,,	86
Do.	$\frac{3}{4}$	,,	$\frac{3}{4}$	,,	$47\frac{1}{4}$	,,	84
Do.	$\frac{7}{8}$	,,	$\frac{7}{8}$	,,	$62\frac{3}{4}$	,,	82
Do.	1	,,	1	,,	80	,,	80

$$P = d \times t \times c.$$

Approximately diam. × thickness × 88 = pressure in tons;
or, area of cut surface × 28 = ditto

237. Steam Hammers.

Weight of hammer in lbs. for shaft forging = 80 × diam. shaft inches ^{2}.

Weight of anvil = 10 times weight of hammer.

238. Steel Forging Presses.

Pressure required = 16000 lbs. per square inch on the die.

SECTION VII.

POWER TRANSMISSION BY BELTS, ROPES, CHAINS, AND GEARING.

239. Transmission of Motion.

By *rolling contact*, as spur wheels and pinions, crown wheel and pinion, face wheel and lantern, bevel wheels, cones, rack and pinion, &c.

By *sliding contact*, as inclined plane, wedge, cams, swash plate, crown wheel escapement, screw, &c.

By *wrapping contact*, as cords and pulleys, belts and pulleys or riggers, speed pulleys, capstan, fusee of watch, &c.

By *link work*, as levers, cranks, treadle of lathe, &c.

—*Tomkins*' '*Machine Construction*.'

240. Notes on Belt Gearing.

Coefficient of friction between ordinary leather belting and cast-iron pulleys or drums = ·423. Ultimate strength

of ordinary leather belting = 3086 lbs, per sq in. Belts vary from $\frac{3}{16}$ inch to $\frac{1}{4}$ inch thick, average $\frac{7}{32}$ inch. The strongest part is $\frac{1}{3}$ of the thickness on the flesh side.

	Breaking Strain.	Safe Working Strain.
Through solid part ..	.. 675 lbs. ..	225 lbs. per in. wide
Through riveting	.. 382 lbs. ..	127 ,, ,, ,,
Through lacing ..	.. 210 lbs. ..	70 ,, ,, ,,

The working strength of the belt must be taken as that of its weakest part, which is the lacing.

The tension of the driving side, which must not exceed the safe working strength of the belt = force transmitted + mean normal tension.

The force transmitted = the difference between the tension of the driving side and the tension of the following side. —*Welch's 'Designing Belt Gearing.'*

When the arc of contact = 180°, the force able to be transmitted may be taken as 50 lbs. per inch wide. If more or less than $\frac{1}{2}$ circumference be embraced by belt, the force transmitted may be increased or reduced by about 2·8 lbs. for every 10° difference from 180°.

The sum of the tensions, or cross strain on shafting, may be taken as 90 lbs. per inch wide.

The lower side of a belt should be made the driving side when possible, so that the arc of contact may be increased by the sagging of the following side.

To increase the capability for transmission of power, the diameters of the pulleys may be increased, retaining the same ratio, the increase of power being obtained by the increased velocity alone.

Wide belts are less effective per unit of sectional area than narrow belts. A belt should never exceed 18 inches wide. Long belts are more effective than short belts. All belts should hang slack when not in use.

The velocity of lathe belts should be from 25 to 50 feet per second, = 1500 to 3000 feet per minute.

Convexity of pulleys to receive belt = $\frac{1}{2}$ inch per foot wide, turned with a broad tool and coarse feed to give a non-slipping surface.

The proportion between the diameters of two pulleys working together should not exceed 6 to 1.

Width of pulley = $\frac{1}{4}$ more than belt.

Ordinary shop shafting 100 revns. per min.: belting say 1000 to 1500 ft. per min.

The revns. per min. of two pulleys embraced by the same belt will be inversely proportional to their diameters.

Pulleys from 2 to 3 ft. diam. transmit approximately 1 H.P. per inch width of belt at ordinary velocities; or sq. ins. belt in contact with pulley × velocity ft. per min. ÷ 72000 = H.P.

241. Strength of Leather Belts.

H.P. = Effective horse power transmitted.
v = velocity of belt in ft. per min.
w = width in ins. of single belt.

$$\text{H.P.} = \frac{w\,v}{470}. \qquad w = \frac{470\ \text{H.P.}}{v}.$$

For double belts multiply H.P. × 1·5 or $w \times \frac{2}{3}$.

—*Bagshaw & Sons, Batley.*

Another rule:—

R = revns. per min.

D = diam. pulley ft. $\qquad \text{H.P.} = \frac{w\,\text{D}\,\text{R}}{150}.$

Another rule:—

Single belt, $w = 1100\ \text{H.P.} \div v$.
Double belt, $w = \frac{6}{10} \times 1100\ \text{H.P.} \div v$.

Another rule:—

$$\text{H.P.} = \cdot 0015 \times v.\ \text{ft. min.} \times w.\ \text{ins.}$$

242. Large Double Belts.

w = width of double belt in ins.
v = velocity ft. per second.
l = length ins. of arc of contact on lesser pulley.
H.P. = horse-power transmitted.

$$w = \frac{66000 \times \text{H.P.}}{l \times v}.$$

—*Evan Leigh.*

Double belts should not be used over pulleys less than 3 ft. 6 in. diam.

243. Notes on Hemp Ropes.

Italian hemp ropes are stronger than Russian hemp.

New white ropes are stronger and more pliable than tarred ropes, but the latter retain their strength for a longer period owing to the protection afforded against atmospheric influences. The quantity of tar found most suitable is about 15 per cent of the weight of the rope.

Tarred ropes are stiffer than white by about $\frac{1}{6}$, and in cold weather somewhat more.

Ropes which have been some time in use are more flexible than new ones; the stiffness of ropes increases after a little rest.

Wet ropes, if small, are a little more flexible than dry; if large, a little less flexible. Ropes shorten and swell when wetted. A wet rope, or one saturated with grease, loses half its strength.

There is considerable loss of strength from strain, and exposure after use, although a rope may appear perfectly sound.

Ropes are usually measured by their circumference: hence a 6-inch rope is one 6 inches in circumference, or about $1\frac{7}{8}$ inch diameter.

All ropes should be kept dry and free from lime.

Round ropes are better than flat for all purposes.

Ultimate strength of new white ropes is about 6000 lbs. per square inch sectional area, but good ropes may stand 10,000 lbs. per square inch.

Double rope slings are not twice the strength of single rope, owing to inequality of strain; but in a rope fall with sheaves in good order, each fold of the rope may be counted for the strength.

The work absorbed in bending a rope fall over a sheave varies with the quality of the rope, directly as the tension, as the diam.^{2}, and inversely as diam. of sheave, and is irrespective of velocity.

Include weight of running block in calculating load on fall, and both blocks together with the rope, in weight on strop. Snatch block makes practically no difference in lifting power, if it has a good lead.

In rope tackle it is usual to allow for the friction in bending round sheaves, &c. = $\frac{1}{3}$ of the load to be lifted.

244. Formulæ for Strength of Hemp Ropes.

Breaking weight new rope,		cwts.	= circumference^2 × 5.	
Safe load on	,,	,,	= wt. lbs per fath. × 3.	
B.W. new stretched rope in		,,	= (diameter in $\frac{1}{8}$ths)^2.	
Safe load	,,	,,	= wt. lbs. per fath. × 4.	
,, on new rope fall		,,	= circumference^2.	
,, good	,,	,,	= $\frac{2}{3}$	,,
,, old	,,	,,	= $\frac{1}{2}$	,,
Weight of clean dry rope per fathom, in lbs.			= $\frac{1}{4}$	,,

Minimum diameter of sheave in inches .. .. } = circf. rope + 2 ins.

Flat ropes, width about 4 times thickness

„ wt. lbs. per fath. approx. = circf. × 2.

„ B.W. tons = wt. lbs. per fathom.

245. Hide Ropes

Made by G. Pitts & Sons, Kirkdale, Liverpool, for hand-power delivery cranes, at 1*s.* 10*d.* per lb.

Dipped in Stockholm tar to prevent destruction by rats.

$$\frac{\text{Circf.}^2}{5} = \text{wt. lbs. per fathom.}$$

246. Fly Ropes.

When power is transmitted over considerable distances by an endless rope running at a high velocity the rope is called a fly rope. Much used in engineering shops for driving travelling cranes, carrying heavy pieces of machinery. A 3-ply Manila rope, or cotton rope, with beeswax well rubbed in together with a little blacklead, is best. Run 3000 to 5000 ft. per minute in cast iron pulleys with V-grooves, angle 30° to 45°. Working strain transmitted about 50 lbs. per circular inch area. Rope tightened by jockey pulley giving about 300 lbs. per cir. in. stress. Supported every 10 or 12 feet by flat plates of chilled cast iron. Friction of pulleys is inversely as their diameter, they should be not less than 30 times diam. of rope. By experiment a new rope ½ inch diam. stretched 1 inch per ft. per cwt.

247. Rope Driving.

a = sectional area of rope in sq. ins.

s = speed in ft. per min.

n = number of ropes

H.P. = effective horse-power transmitted.
c = constant = hemp 100

$$\text{H.P.} = \frac{c\,a\,n\,s}{33,000}; \qquad a = \frac{33,000\ \text{H.P.}}{c\,n\,s}.$$

—*J. Bagshaw & Sons, Batley.*

248. Curve of Rope.

A rope or chain when deflected by its own weight hangs in a catenary curve. It approximates to a parabola and is indistinguishable from one when the deflection is not more than one-tenth of the span.

249. Tests of Ropes.

	Ultimate tension tons per sq. in.	Elongation. per cent.
White hemp	4·75	18
Tarred hemp	3·5	16
White Manila	4·5	15
White aloes	2·5	..
Esparto and cocoa fibre	1·0	..
Flat ropes, hemp or Manila tarred	3·5	5

Round ropes with moderate attention may be worked at a stress equal to one-third breaking stress, and flat ropes at one-fourth.

250. Average Tensile Strength of Ropes.

Specimens 13 ft. long, ends wound on grooved pulleys.

	lbs. per sq. in.
White hemp	10,500 to 11,200
Tarred hemp	7,700 „ 8,400

	lbs. per sq. in.
White manila	9,800 to 10,600
White aloes	5,600 „ 7,000
Flat, tarred hemp, or manila	7,800 „ 8,400
Unannealed wire rope	55,000
(elongation 6 to 8 per cent.)	
Annealed wire rope	45,000
(elongation 12 to 15 per cent.)	

Factor of safety 3 to 4.

—*A. Duboul.*

251. Experiments on Wire Rope at Forth Bridge.

Crucible cast steel wire rope was used. With a diameter of sheave = 6 times *circumference* of rope, rope bent over sheave 5000 times before failure commenced, 15,000 before final destruction.

With a diameter = 8 times circumference, 10,000 times and 36,000 respectively.

252. Lang's Patent Wire Ropes.

	Bessemer steel.	Crucible steel.	Patent steel.	Plough steel.
Strength of material in tons per sq. in.	45	56	75	111
Round rope, 6 strands of 6 wires each, up to	4 in. circf.	3 in.	$3\frac{1}{2}$ in.	4 in.
	9 wires in each strand above these sizes.			
Approx. B.W. in tons = $c^2 \times$	1·5	2	2·5	3.5

Working load .. = $\frac{1}{10}$th breaking weight.

Weight of round wire ropes in lbs. per fathom = circf.$^2 \times \frac{7}{8}$.

—*J. Bagshaw & Sons, Batley.*

253. R. S. Newall & Co.'s Wire Ropes.

Round—Wt. lbs. per fath. $= C^2 \times \frac{7}{8}$

B. W. tons $=$ wt. lbs. fath. $\times 2$

Safe load cwts. $=$ do. $\times 6$

Steel ropes $2\frac{1}{2}$ times stronger.

Flat—Width $= 4\frac{1}{2}$ to $5\frac{1}{2}$ times thickness.

Sectional area $\times 10 =$ wt. lbs. per fath.

Wt. lbs. fath. $\times \frac{9}{5} =$ B. W. tons.

B. W. tons $\times \frac{20}{9} =$ safe working load cwts.

Drum for wire rope = 2′ 6″ diameter for every $\frac{1}{8}$ inch diameter of rope, speed 30 to 50 miles per hour. For slow speeds drum 80 times diameter of rope.

254. Strength of Chains.

d = Diameter of iron in $\frac{1}{8}$ths of an inch.			Example ¾ chain. tons.	cwts.
B.W. in tons, B.B. short-link crain chain ..	=	$\frac{1}{2}d^2$	18	0
,, ,, ordinary chain	=	$\frac{2}{5}d^2$	14	8
,, ,, ,, ,, (Anderson) ..	=	$\frac{3}{8}d^2$	13	10
Elswick test in tons, 10 per cent. above Admiralty proof	=	$\frac{33}{160}d^2$	7	$8\frac{1}{2}$
Admiralty proof strain in tons	=	$\frac{3}{16}d^2$	6	15
Safe load in tons (Molesworth, 11th. edit.) ..	=	$\frac{1}{8}d^2$	4	10
Safe load at 5 tons per square inch sectional area	=	..	4	$8\frac{1}{2}$
,, ,, in tons (Molesworth, 21st. edit.) ..	=	$\frac{1}{9}d^2$	4	0
,, ,, in tons, common rule	=	$\frac{1}{10}d^2$	3	12
Maximum temporary load on good annealed chain in cwts.	=	$2d^2$	3	12
Safe load, ordinary chain (Anderson), in tons ..	=	$\frac{3}{32}d^2$	3	$7\frac{1}{2}$
,, for ordinary cranes, in cwts.	=	$1\frac{1}{2}d^2$	2	14
,, at 3 tons per square inch sectional area	=	..	2	13
,, coal cranes, in cwts.	=	$1\frac{1}{4}d^2$	2	5
,, old chain, quality and condition unknown	=	d^2	1	16
Weight in lbs. per fathom, short-link crane chain	=	d^2	36	
,, ,, ,, ordinary ,,	=	$\cdot 88d^2$	$31\frac{1}{2}$	

Safe load (5 ton cranes and upwards) in tons $= \frac{1}{8}d^2$
When made of good iron, but large chains are frequently of common quality.

Size of links for crane chains	$= 3\frac{1}{3}d \times 4\frac{2}{3}d$
Admiralty proof strain on rings	$= d$ in $\frac{1}{8}$ths$^2 \div 16$
" " " stud chain	$= d$ in $\frac{1}{8}$ths$^2 \times \cdot 281$
Common chain cables, B.W. lbs.	$= 1{,}000{,}000\ (\frac{1}{4}d)^2$

255. Remarks on Crane Chains.*

$\frac{9}{16}''$ B. B. tested short link crane chain (Crown S. C.) should break with a load of 13 tons, if the iron bar from which it is made break with 26 tons per square inch ultimate stress; but a test piece of the chain 4 feet long breaks usually with a load of 9 to 10 tons, generally opening at the welds. Each chain is tested before use with a maximum load of $4\frac{1}{2}$ tons, examined link by link and used on Hydraulic Coal Cranes to lift maximum gross load of $1\frac{1}{4}$ tons, examined again at frequent intervals and annealed; any links reduced by wear to $\frac{1}{2}$ an inch at ends are condemned as worn out; worn links cut out and remainder used down to same limit. A good chain, properly looked after, will make from 100,000 to 150,000 lifts before it is entirely worn out. These chains occasionally fail in use, although the factor of safety adopted allows so great a margin.

256. Examination of Chains at the Docks in London.

All chains are taken down, annealed and examined as follows, viz.:—

Hydraulic crane, lead, lift, &c., chains, every six months.

* See paper on "Use and Care of Chains for Lifting and Hauling," read by the author before the Civil and Mechanical Engineers' Society, 1887.

Hand and steam crane, traveller, dockgate, and chain gear, every twelve months.

The chain gear comprises chain runners, chain necklaces, sweeping and guy chains, chain slings, cattle slings, shackles, dogs, and lead hooks.

257. Notes on Toothed Gearing.

Pinions, wheels, and racks are made of cast iron, cast steel, and malleable cast iron; the latter is strong, but liable to twist or warp. Pinions are sometimes made of wrought iron; small gearing is frequently made of gun metal.

Gearing is increased in strength by shrouding or flanging up to pitch line.

The comparative wear of gearing is inversely proportional to the number of teeth; hence, pinions wear quicker than wheels.

Two teeth on a pinion or wheel is the minimum number in gear at one time, each bearing half the total load.

The *power* capable of being transmitted by gearing depends, within reasonable limits, entirely upon the *speed*; the *pressure* (at pitch line) depends upon the *pitch*.

The speed should not exceed 1800 ft. per min. circumferential velocity for ordinary cast iron wheels, or 2400 for mortise wheels.

The velocities of geared wheels are in the inverse ratio of their diameters.

The transmission of the power strains the teeth as cantilevers, or $s = \frac{b\,d^2}{l}\,c$, c for cast iron safe load $= 600$.

The working load should not exceed $\frac{1}{10}$th of the breaking weight.

The dimensions of the teeth are proportional to the

pitch; hence, in ordinary proportions the strength is represented by $p^2\,c$, c for cast iron being 1000.

The breadth of tooth on face beyond a certain amount, say twice the pitch, cannot be reckoned upon for strength, owing to irregularities in the teeth, and probability of unequal bearing.

258. Strength and Weight of Toothed Gearing.

Safe pressure in lbs. at pitch line on wheel teeth of average proportions:—

Cast iron, little shock, $= 625 \times$ pitch^2.
„ moderate shock, $= 400 \times$ pitch^2.
„ excessive shock, $= 277 \times$ pitch^2.

The latter case also applies to the iron teeth of mortise wheels, which are made thinner than ordinary teeth of same pitch.

Breadth of teeth $= 2$ to $2\frac{1}{2}$ times pitch.

The weight of toothed gearing in lbs. approximately, is for spur wheels $\cdot 38\,n\,b\,p^2$, bevel wheels $\cdot 325\,n\,b\,p^2$.

259. Formulæ for Strength of Gearing.

s = strain in lbs. to be transmitted, calculated at pitch circle.
p = pitch in inches.
c = constant, when teeth of ordinary proportion =

Material.	Plain.	Shrouded.
Cast steel	4000	6000
Wrought iron..	3000	4500
Malleable cast iron ..	2000	3000
Gun metal	1500	2000
Cast iron..	1000	1500

$$s = p^2 c. \qquad p = \sqrt{\frac{s}{c}}.$$

For slow speeds and uniform pressure, c may be increased one-fourth.

260. Wheel Gearing, Manchester Pitch.

Diametral pitch (Manchester pitch) =

$$\frac{\text{No. of teeth}}{\text{Diam. of pitch circle in ins.}}$$

$$\text{Circular pitch} = \frac{\pi}{\text{diametral pitch.}}$$

or (tooth + space) in inches.

No. of teeth in wheel = diameter × diametral pitch.

$$\text{Diameter of wheel} = \frac{\text{No. of teeth}}{\text{diametral pitch}}.$$

Addition to diameter for increased No. of teeth =

$$\frac{\text{No. to be added}}{\text{diametral pitch}}.$$

$$\text{Outside diameter of wheel} = \frac{2}{\text{diametral pitch}} +$$

diameter pitch circle.

For example:—A 10-pitch wheel (Manchester or diametral pitch) 7·5 ins. diam. will have $10 \times 7{\cdot}5 = 75$ teeth; another in the same set 4 ins. diam. would have $10 \times 4 = 40$ teeth, and their true pitch would be $\frac{3{\cdot}1416 \times 7{\cdot}5}{75} = \frac{3{\cdot}1416 \times 4}{40} = {\cdot}31416$ ins., or generally, with n pitch wheels, true pitch $= \frac{\pi}{n}$ inches.

261. Mill Gearing.

H = H.P. actual.	p = pitch inches.
b = breadth on face inches.	R = revolutions per min.
D = diam. in feet.	n = no. of teeth.

$$H = \frac{p^2\,b\,D\,R}{306} \qquad p = \sqrt{\frac{306\,H}{b\,D\,R}}$$

$$D = p \operatorname{cosec}\frac{180^\circ}{n} \qquad p = \frac{D}{\operatorname{cosec}\frac{180^\circ}{n}}$$

Another formula:—

$$\text{N.H.P.} = \sqrt{(D\,R)} \times p^2\,b \begin{cases} \cdot 05 \text{ wood} \\ \cdot 043 \text{ cast iron} \\ \cdot 15 \text{ cast steel.} \end{cases}$$

Gudgeons (*Tredgold*)

$$\text{d. ins.} = \frac{\sqrt[3]{w.\text{ lbs.} \times l.\text{ ins.}}}{9}$$

262. Power of Craneman, &c.

Radius of handle	1 ft. 3 in. to 1 ft. 6 in.
Height to centre of axle ..	2 „ 6 „ „ 3 „ 0 „
Height from ground to path of handle	1 „ 6 „ „ 1 „ 9 „
Revns. of handle per min.	28 to 23
Speed at circumference of handle for continuous work while lifting ..	220 ft. per min.
Do. do., when lifting and lowering ..	330 „ „
Force of ordinary labourer on handle ..	12 lbs, + friction
„ „ craneman „ ..	15 „ „
Maximum ditto, for short time say 5 min. at 440 ft. per min. ..	30 „ „

At 8 hours per day, on long lifts, the effective work averages 2380 to 2420 ft. lbs. per min. per man.

One man can raise 1 ton with a multiplying power of 150, the friction being about $6\frac{1}{2}$ lbs. and the effective pressure 15 lbs. making the gross pressure on the handle $21\frac{1}{2}$ lbs., or coefficient = ·7.

Speed of lifting with hand-power crane = 2 ft. per sec.

In raising weights with a pulley a man can maintain a downward pull of 40 lbs. permanently, and equal to his own weight temporarily.

263. Differential Pulley Calculations.

D = diam. of larger pulley. d = diam. of smaller pulley.

$$D : \frac{D-d}{2} :: W : P \therefore P = \frac{W \times (D-d)}{2\,D}.$$

M = modulus or efficiency of machine, then W × M = actual load lifted. Load will not lower by itself when M is less than ·5.

By experiment with various differential pulleys—

Load.	Multiplying power.	Coefficient.
5 cwt.	16 to 1	·4
10 „	30 „ 1	·33
30 „	53 „ 1	·25

264. Hand Power Crane.

W = load in lbs.
P = power required in lbs. to overcome load.
F = friction of gearing of crane without load.
f = friction of gearing due to load.

M = multiplying power of gearing.
E = efficiency of crane under various loads

$$P = F + f + \frac{W}{M}.$$

$$E = \frac{W}{MP} = \cdot 5 \text{ to } \cdot 75$$

By experiment—

$$M = 40,\ F = 4 \cdot 21 \text{ lbs.},\ f = \cdot 0179\ W.$$

—*R. S. Ball.*

1 ton crane, 4 men at handles, 25 lbs. each man, multiplying power 24 to 1.

Delivery cranes, short lift, lowering by brake, allow 25 lbs. for each man, handle 16″ radius, 30 revolutions per minute, coefficient ·75.

Landing cranes, long lift, allow 15 lbs. for each man.

265. Determining the Proportions of Gearing.

In toothed gearing exact ratios should be sacrificed to obtain numbers prime to each other. When the wheels are to be equal, one of them should have an additional tooth called a "hunting-cog"; then each tooth of the one will encounter each tooth of the other, equally often, and equalise the wear.

Numbers are prime to each other when they have no common measure, i.e., cannot both be divided without remainder by any number except 1.

For wheels to gear properly the number of teeth in each must be proportionate to their diameters, in other words their pitch must be equal.

266. Proportions of Wheel Teeth.

	Parts.	Per cent.	Other authorities.		
Pitch	15	or 100	100	100	100
Whole length of tooth	12	„ 80	60	75	75
Pitch line to point	$5\frac{1}{2}$	„ 36·6	25	33	35
„ to root	$6\frac{1}{2}$	„ 43·3	35	42	40
Thickness at pitch line	7	„ 46·6	48	$48\frac{1}{2}$	45
Width of space at ditto	8	„ 53·3	52	$51\frac{1}{2}$	55

Curve .. .. radius = pitch, or cycloidal.
Breadth of tooth on face .. .. .. 250 per cent.
Thickness of rim .. ..
Projecting rib inside ditto .. .. .. } 44 to 50
Thickness of arms .. ..
Breadth of arms at rim 175
„ of taper increasing to boss .. $\frac{1}{2}$ inch per foot
Thickness of rib on arms 25
„ metal in boss .. .. .. 75 to 80

267. Ordinary Proportions of Keys.

$$\text{Width of key} = \begin{cases} \frac{1}{4} \text{ diam. of shaft up to 4 inches.} \\ \frac{1}{5} \quad\text{„} \quad 4 \text{ inches to 8 inches.} \\ \frac{1}{6} \quad\text{„} \quad 8 \quad\text{„}\quad 12 \quad\text{„} \end{cases}$$

Key square at thick end. Taper $\frac{1}{4}$ inch per foot.
One-third of thickness let in shaft, remainder in wheel.

268. Proportions of Cotters through Bars.

b = Breadth of cotter.
t = Thickness of cotter.
d = Diameter of bar.

Through round bars,

$$b = 1 \cdot 4635\, d. \; t = \frac{d}{5}.$$

Through square bars,

$$b = 1 \cdot 5 \text{ side of bar.} \quad t = \frac{\text{side of bar}}{4}.$$

269. Journals for Shafts and Axles.

Length of brass = 0·9 to 1·0 length of journal. Less liable to score in wearing, if slight end play can be given.

Thickness and projection of collar and radius of curves =

$$\frac{d}{8} + \frac{1''}{8} \text{ to } \frac{d}{10} + \frac{1''}{8}.$$

Coefficient of friction (μ), average ·08; but under favourable conditions may be as low as ·01.

Work expended in friction in foot lbs. per min. =

$$\mu \, W \frac{\pi}{12} \, d \, R = \cdot 021 \; W \; d \; R.$$

Heat units to be dissipated per min. $= \frac{U}{J}$, (J = 772).

Length of journal depends upon the load and speed, length being increased for high speeds.

$$l = \frac{W \,(50 + \text{vel. ft. per min.})}{70{,}000 \; d.} \; (\textit{Bourne}), \text{ or}$$

$$l = d \,(\cdot 004 \; R + 1) \; (\textit{Unwin}).$$

$$l = \frac{W \; R}{250{,}000 \text{ to } 300{,}000} \text{ or } l = \cdot 4 \text{ to } \cdot 33 \; \frac{\text{I.H.P.}}{\text{rad. crank in.}}$$

Increasing diameter increases friction, because the rubbing surface has further to travel in one revolution.

Increasing length reduces the friction per sq. in., but does not affect the total friction, because for a given space passed through, with a constant load, the friction is independent of surfaces in contact.

When an overhanging journal is increased in length the diameter must also be increased slightly, to give same strength as before, $D = d\sqrt[3]{\frac{L}{l}}$. Pressure on bearings per square inch longitudinal section may be $= \frac{70,000}{50 + v.\text{feet min.}}$, but must never exceed 1000, maximum say 800 in engines.

SECTION VIII.

FRICTION AND LUBRICATION.

270. Laws of Friction.

The friction between two surfaces, dry or only slightly greasy, is in direct proportion to the force with which they are pressed together (within the limits of abrasion), and is independent of the area of the surfaces in contact. With ample lubrication the friction is reduced, but the heavier the pressure per unit of surface the greater must be the consistency of the lubricant, to prevent it from being squeezed out.

The friction between two surfaces at rest is slightly greater than when they are in motion, but when in motion the friction is independent of the velocity so long as the surfaces are kept cool.

Friction is not a force; being passive, it can only act as a resistance.

271. Definitions of Friction.

The Limiting Angle of Resistance ϕ is the angle through which any surface requires to be lifted from the horizontal

to cause a body to be on the point of sliding (friction of rest) or to continue sliding (friction of motion). Its magnitude is fixed by the physical nature of the surfaces in contact. It is also the angle from the vertical made by the resultant of the force or forces acting upon a body when sliding is just about to take place or is taking place.

The Coefficient of Friction μ is the ratio of the pressure P required to overcome the friction of a body on any given horizontal surface, to the whole load W of and on the body $\left(\mu = \frac{P}{W}\right)$. Trigonometrically it is equal to the tangent of the limiting angle of resistance ($\mu = \tan \phi$).

It has been proposed to call the "friction of rest" *stiction*, to distinguish it from the "friction of motion," which would be called *friction*. The common term for the "friction of rest" is statical friction.

272. Morin's Experiments on Friction of Motion.

Dry—

Wrought iron on brass	·172	Brass on wrought iron	·161
Cast " "	·147	" cast "	·217

Greasy—

Wrought " "	·160	" wrought "	·166
Cast " "	·132	" cast "	·107

Lubricated with olive oil—

Wrought " "	·078	" wrought "	·072
Cast " "	·078	" cast "	·077

Oak upon elm dry = $\frac{5}{9}$ of friction of elm upon oak dry.

Note.—These results reduced from General Morin's experiments appear to be very questionable, and indicate the necessity for further investigation.

273. Prof. Ball's Experiments on Friction.

Pine upon pine, grain crossed, slide 9 inches × 9 inches, load 14 to 112 lbs. in motion.

$$\mu W = 1 \cdot 44 + \cdot 252 \, W.$$

274. Mean Coefficients of Friction.

Wood on wood or metal—dry, ·4 to ·6; greasy, ·2 to ·4; lubricated, ·1 to ·2.

Metal on metal—wet, ·3; dry, ·2; greasy, ·15; lubricated, ·1 standing, or ·08 moving.

Leather on metal, wet ·25, dry ·5.

Friction of motion = friction of repose × ·7.

Friction varies with the nature of the surfaces, the lubricant, and the temperature.

Unguents should be thick for heavy pressures, that they may resist being forced out; and thin for light pressures, that their viscidity may not add to the resistance. (Rankine).

In estimating the power to overcome friction, the friction of rest must be taken; but in estimating the effect of friction as a power to resist motion, say a brake strap, the friction of motion must be taken.

275. Action of Oils on Metals.

The results of 12 months' experiments, by Prof. Redwood, show that—

Iron is least affected by seal oil, very little by rape oil, and most by tallow oil.

Brass is not affected by rape oil, least by seal oil, and most by olive oil.

Tin is not affected by rape oil, or whale oil, least by olive oil, and most by cotton-seed oil.

Lead is least affected by olive oil, and most by whale oil; but whale, lard, and sperm oils all act to very nearly the same extent on lead.

Zinc is not acted on by mineral lubricating oil, least by lard oil, and most by sperm oil.

Copper is not affected by mineral lubricating oil, least by sperm oil, and most by tallow oil.

Mineral Lubricating Oil has no action on zinc and copper, acts least on brass, and most on lead.

Olive Oil acts least on tin and most on copper.

Rape Oil has no action on brass and tin, acts least on iron, and most on copper.

Tallow Oil acts least on tin and most on copper.

Lard Oil acts least on zinc and most on copper.

Cotton-seed Oil acts least on lead and most on tin.

Sperm Oil acts least on brass and most on zinc.

Whale Oil has no action on tin, acts least on brass, and most on lead.

Seal Oil acts least on brass and most on copper.

From the foregoing results it will be seen that mineral lubricating oil has, on the whole, the least action on the metals experimented with, and sperm oil the most.

For lubricating the journals of heavy machinery, either rape or sperm oil is the best oil to use in admixture with mineral oil, as they have the least effect on brass and iron, which two metals generally constitute the bearing surfaces of an engine. Tallow oil should be used as little as possible, as it has considerable action on iron.

276. Traction, or Friction on Roads.

Cart on common road $= \frac{1}{30}$ load
Carriage on plank road $= \frac{1}{100}$ „
Do. on railroad $= \frac{1}{300}$ „

SECTION IX.

THERMODYNAMICS, AND STEAM.

277. Rankine's Dynamical Theory of Heat.

Each atom of matter consists of a nucleus or central physical point enveloped in an elastic atmosphere, which is retained in its position by forces attractive towards the nucleus or centre.

The elasticity due to heat arises from the centrifugal force of revolutions or oscillations among the particles of the atomic atmospheres; so that quantity of heat is the *vis viva* of those revolutions or oscillations.

The medium which transmits light and radiant heat consists of the nuclei of the atoms vibrating independently, or almost independently, of their atmospheres. So that the absorption of light and radiant heat is the transference of motion from the nuclei to their atmospheres, and the emission of light and radiant heat the transference of motion from the atmospheres to their nuclei.

278. Sources of Heat.

Friction, Percussion, Mechanical stress, Chemical action, Electrical action.

279. Sensible Heat.

The *Temperature* of a body is its thermal state considered with reference to its power of communicating heat to other bodies.—*Maxwell.*

This is commonly called its sensible heat.

For purposes of measurement some definite effect produced by heat must be selected, e. g. the alteration in length or volume of a substance which expands and contracts uniformly when heated or cooled.

At all ordinary temperatures the ratio of increment in volume to increment in absolute temperature is practically constant in the case of mercury, it is moreover a liquid at such temperatures, and easily measured; hence the *Mercurial Thermometer* is that most commonly used for determining the temperature of a body.

280. Comparison of Thermometers.

	No. of Degrees between freezing and boiling point of Water.	Absolute zero of Temperature.*	Freezing point of Water.	Point of maximum density of Water.	Boiling point of Water.
Great Britain and America: Fahrenheit = F. ..	180	−461·2 (Box − 458·4)	32	39·1	212
Sweden, France, &c.: Centigrade or Celsius = C.	100	− 274	0	4	100
Russia and Spain; Réaumur = R... ..	80	−219·2	0	3·2	80

* Or point of absolute negation of heat.

$$\therefore\ 9^\circ \text{ F.} = 5^\circ \text{ C.} = 4^\circ \text{ R.}$$

To convert from one scale to another,

$$F^\circ = \tfrac{9}{5}\,C^\circ + 32,\quad C^\circ = \tfrac{5}{9}\,(F^\circ - 32),\quad R^\circ = \tfrac{4}{9}\,(F^\circ - 32)$$
$$F^\circ = \tfrac{9}{4}\,R^\circ + 32,\quad C^\circ = \tfrac{5}{4}\,R^\circ,\qquad R^\circ = \tfrac{4}{5}\,C^\circ.$$

281. Effect of Change of Temperature

All bodies expand by heat and contract by cold, i. e. expand by addition of heat and contract by loss of heat; more precisely—change of temperature alters the relation between the attractive and repulsive forces of the atoms of a solid body, and therefore alters the distance at which they would remain in equilibrium, neither attracting nor repelling each other. In the case of gases the atoms repel each other at all temperatures, and the effect of a change of temperature is to alter the amount of the repulsive force and pressure upon the containing vessel, increasing them with increase of temperature, and *vice versa.*

282. Transfer of Heat.

Radiation of heat is the transfer which takes place between bodies at all distances apart, in the same manner and according to the same laws as the radiation of light.

The intensity of radiant heat diminishes as the square of the distance from the radiating body.

Conduction is the transfer of heat between two bodies, or parts of a body, which touch each other.

Convection, or carrying of heat, means the transfer and diffusion of the state of heat in a fluid mass by means of the motion of the particles of that mass.

283. Mechanical Equivalent of Heat.

British Thermal Unit, or unit of heat, is the quantity of heat required to raise 1 lb. of pure water, at its point of maximum density (= 39·1° F.), through 1° F.

Joule's Equivalent is the mechanical effect resident in one thermal unit = 772 foot-lbs.

When the centigrade scale is used, the point of maximum density of water will be 4° C., the thermal unit the quantity of heat required to raise 1 lb. water through 1° C., and its mechanical equivalent 1390 foot-lbs.

The Quantity of Heat involved in any operation may be expressed directly by its mechanical equivalent in foot-lbs.

284. Capacity of Bodies for Heat.

Capacity for heat (Irvine) of a body is the number of units of heat required to raise one pound weight of the body one degree in temperature.

285. Specific Heat.

The *Specific Heat* (Gadolin) of a body is its capacity for heat compared with that of an equal weight of water. It is the quantity of heat requisite to change its temperature any stated number of degrees ($= a$) compared with that which would produce the same effect on water at 60° F., and 30″ bar. ($= b$), and it is therefore expressed by the fraction $\frac{a}{b}$, which may be made referable to weight or volume.

If a unit mass of a substance absorbs a quantity of heat q in passing from a temperature T, to a temperature $T + t$, then the ratio q/t is termed the ***mean specific heat for $t°$ from the temperature*** T.

The limit of the ratio q/t, as t is diminished, is termed the ***true specific heat at the temperature*** T.

The specific heat of all bodies (except gases) increases slightly with the temperature.

The specific heat and the atomic weight of simple bodies are inversely proportional to each other, so that their product is in all cases constant.

286. Latent and Sensible Heat.

Latent heat (Black 1757) is the heat absorbed or disengaged by a body without alteration of temperature, upon a change of state or alteration in the aggregation of its molecules.

Dr. Black's theory of the latent and sensible heat of steam was that the sum of the two was constant at all temperatures.

Regnault's experiments showed that the total heat was not constant, but increased slowly with increase of temperature, and was equal in F.° to

$$\left\{(\text{Sensible temperature in F.}^\circ - 32 \times \cdot 305)\right\} + 1123 \cdot 7$$

287. Gases and Vapours.

Permanent gases are those which cannot be liquefied.

Ordinary gases are those which do not liquefy at ordinary temperatures or pressures, and the farther they are removed from their point of liquefaction the nearer they approach the character of permanent gases.

Vapours are gases near their point of liquefaction. Ordinary high or low pressure steam is a vapour, superheated steam is a gas.

The temperature being constant, the volume of a gas is inversely as its pressure.

The product of the volume and pressure of any gas is proportional to the absolute temperature.

$$\left.\begin{array}{l} v = \text{vol. of a perfect gas} \\ t = \text{absolute temperature} \\ p = \quad\text{,,}\quad \text{pressure} \end{array}\right\} \frac{v\,p}{t} = \text{constant.}$$

In raising the temperature of a gas under pressure, mechanical work is done in providing the necessary space

When a gas is heated, the expansion is about $\frac{1}{273}$ of its volume at 0° C. for each ° C. increase of temperature, or permanent gases expand ·00202 of vol. for each F° increase of temperature from 32° F under a constant pressure.

Vapour of water is absorbed by the air at all temperatures, the higher the temperature of the air the more water it is capable of holding in solution.

288. Laws of Gases.

Boyle's Law (1662), also enunciated by Marriotte (1676). The volume of a gas varies inversely as the pressure. It may also be stated thus: the pressure of a gas is proportional to its density. The law is most nearly fulfilled when the temperature of the gas is farthest removed from its point of condensation.

Charles' Law (1787), *Dalton* (1801), *Gay-Lussac* (1802). The volume of a gas under constant pressure expands when raised from the freezing to the boiling temperature of water by the same fraction of itself whatever be the volume of the gas (= 1·3665). This law has been found to be true for all other temperatures at which it has hitherto been tested.

v at 32°, and V at $t°$ any gas

$$\text{then } V = v + v \cdot 00202\,(t - 32).$$

289. Volume of a Gas at given Pressure and Temperature.

V = vol. of gas at T° and P lbs.

v = „ „ $t°$ „ p lbs.

$$v = V \times \frac{458 \cdot 4 + t}{458 \cdot 4 + T} \times \frac{P}{p}$$

—*Box, on 'Heat.'*

V = vol. elastic fluid given weight and pressure at 32° F.

V = vol. it will occupy at same pressure at $t°$ F.

$V = v + \cdot 00202\, v\, (t - 32)$

—*Gay Lussac.*

290. Atmospheric Pressure.

The weight of the atmosphere at 60° Fahr. and 30 ins. barometric pressure is 14·6757 lbs. per square inch.

No. of atmos. × ·006557 = tons per square inch.

Absolute pressure is the pressure from zero, or the pressure of the atmosphere added to the indication of the pressure gauge, say gauge pressure + 15 lbs.

All questions of expansion and compression of steam must be worked from absolute pressure or perfect vacuum line of indicator diagram.

1 lb. of air at 32° F and 30 in. bar = 12·384 cubic ft.

291. Pressure and Temperature of Steam.

p = lbs. per sq. in.
t = temperature F°.

1 to 24 atmospheres :—

$$p = (\cdot 2697 + \cdot 006803\, t)^5.$$
$$t = 147\, \sqrt[5]{p} - 39\cdot 644.$$

—*Arago and Dulong.*

1 to 4 atmospheres :—

$$p = \left(\frac{103 + t}{201\cdot 18}\right)^6.$$

$$t = 201\cdot 18\, \sqrt[6]{p} - 103.$$

—*Tredgold.*

1 to 4 atmospheres:—

$$p = \left(\frac{98 \cdot 8 + t}{198 \cdot 56}\right)^6.$$

$$t = 198 \cdot 56 \sqrt[6]{p} - 98 \cdot 8.$$

—*De Pambour.*

292. Relation of Pressure to Temperature of Steam.

p = original pressure (absolute).
t = ,, temperature (F°).
p_1 = new pressure.
t_1 = new temperature.

$$p_1 = p\left(\frac{t_1}{t}\right)^{4 \cdot 4}.$$

$$t_1 = t \sqrt[4 \cdot 4]{\frac{p_1}{p}}.$$

293. Pressure and Volume of Steam by Boyle and Marriotte's Law.

P = original pressure.
p = new pressure.
V = original volume.
v = new volume.

$$p = \frac{\mathrm{P\,V}}{v}, \quad v = \frac{\mathrm{P\,V}}{p}.$$

294. Relative Volume of Steam.

The ratio of the volume of steam to that of the water from which it is produced is called the relative volume.

p = total pressure in lbs. per sq. in.
t = temperature in F°.

V = relative volume for pressures between 6 and 60 lbs.

$$V = 37\,\frac{460 + t}{p}, \quad t = 147\sqrt[5]{p} - 40.$$

By *Boyle and Marriotte's law.*

With constant temperature the volume varies inversely as the pressure $\therefore$ volume $\times$ pressure = constant.

$$V \text{ approximately} = \frac{25{,}000}{p}.$$

By *Navier's modification.*

The temperatures not being constant, in ordinary cases for varying pressures.

$$V \text{ up to 26 lbs. per sq. in.} = \frac{27{,}000}{p+1}.$$

$$V \text{ above } \quad ,, \quad ,, \quad = \frac{30{,}000}{p+4}.$$

By *Pole's formula.*

$$V = \frac{24{,}250}{p} + 65, \quad p = \frac{24{,}250}{v - 65}.$$

By *Hann's formula.*

$$V = \frac{17149 + 37\,t}{p}.$$

295. Properties of Saturated Steam.

Absolute Pressure.	Gauge Pressure.	Sensible Temperature.	Latent Heat.	Total Heat.	Weight of cubic foot.	Relative Volume.
14·7	0·0	212·0	966·1	1178·1	·0380	1642
65	50·3	298·0	906·3	1204.3	·1538	405
70	55·3	302·9	902·9	1205·8	·1648	378
75	60·3	307·5	899·7	1207·2	·1759	353
90	75·3	320·2	890·9	1211·1	·2089	298
115	100·3	338·0	878·5	1216·5	·2628	237

296. Expansion Curves.

An *Isothermal line* is a curve showing the relations between pressure and volume in a fluid while a constant temperature is maintained. For a perfect gas the isothermal line is a rectangular hyperbola in accordance with Boyle's Law.

An *Adiabatic line* is a curve showing the relations between pressure and volume in a fluid while the quantity of heat it contains is maintained constantly uniform.

297. Temperature of Boiling Water and Steam.

The temperature of boiling water varies with its density, purity, pressure, and nature of containing vessel. The temperature of steam from the same or other water will always be uniform for a given pressure.

After water reaches temperature due to pressure, additional heat goes entirely to convert a portion of the water into steam.

298. Heat Required for Evaporation.

Supposing that a certain quantity of water is raised from 32° F. to 212° F. by 1000 units of heat, then it will require 5359 additional units to evaporate this quantity, which is given up again upon the condensation of the steam.

299. Solution and Evaporation of Steam.

1 oz. steam passed into 6·35 oz. water at 60° F. raises temperature to 212° F. Poured into shallow pan and allowed to cool to 60° F., the evaporation will reduce the water exactly to its original weight of 6·35 oz. This experiment has been held to show that the apparent

increase in temperature of water upon application of heat is due to dissolved steam only.—*C. Wye Williams.*

300. First Law of Thermodynamics.

Heat and mechanical energy are mutually convertible; and heat requires for its production, and produces by its disappearance, mechanical energy in the proportion of 772 foot-lbs. for each British unit of heat.—*Rankine.*

When work is transformed into heat, or heat into work, the quantity of work is mechanically equivalent to the quantity of heat.—*Clerk Maxwell.*

Heat and work are mutually convertible and Joule's equivalent is the rate of exchange.—*Jamieson.*

301. Second Law of Thermodynamics.

If the total actual heat of a homogeneous and uniformly hot substance be conceived to be divided into any number of equal parts, the effects of these parts in causing work to be performed are equal.—*Rankine.*

It is impossible, by the unaided action of natural processes, to transform any part of the heat of a body into mechanical work, except by allowing heat to pass from that body into another at a lower temperature.

—*Clerk Maxwell.*

It is impossible for a self-acting machine, unaided by any external agency, to convey heat from one body to another at a higher temperature.—*Clausius.*

It is impossible by means of inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of the surrounding objects.—*Sir W. Thomson.*

Under existing conditions it is impossible to convert the whole of any given quantity of heat into work, and the proportion which can be converted into work follows a

certain ratio determined by the absolute temperature of the source of heat and the lowest surrounding temperatures.—'*Practical Engineer.*'

If an engine be such that, when it is worked backwards, the physical and mechanical agencies in every part of its motions are all reversed, it produces as much mechanical effect as can be produced by any thermodynamic engine, with the same temperature of source and refrigerator, from a given quantity of heat.—*Sir W. Thomson.*

302. Carnot's Law or Function (1824).

The ratio of the maximum mechanical effect to the whole heat expended in an expansive engine, is a function solely of the two temperatures at which the heat is respectively received and emitted, and is independent of the nature of the working substance.

303. Sir W. Thomson's Modification of Carnot's Law (1851).

The efficiency of a perfect heat engine is expressed by the ratio of the difference of the absolute temperatures of the source and condenser, to the absolute temperature of the source; absolute temperature being measured according to a scale so graduated that the temperature of a homogeneous body shall vary in simple proportion to the quantity of energy it possesses in the form of sensible or thermometric heat.

304. Law of Efficiency of Thermodynamic Engines.

The heat transformed into mechanical work, is to the whole heat received as the range of temperature is to the absolute temperature at which it is received.

$$\frac{\tau_1 - \tau_2}{\tau_1} = \frac{T_1 - T_2}{T_1 + 461} \text{ (Fahr.)} = \frac{T_1 - T_2}{T_1 + 274} \text{ (Cent.)}$$

Example:—What is the efficiency of a perfect steam engine working at an absolute initial pressure of 100 lbs. per square inch, corresponding to about 328° F., the temperature of the condenser being 104° F.?

$$\text{Efficiency} = \frac{328 - 104}{328 + 461} = \cdot 283.$$

Same example with the steam superheated to 600° F.

$$\text{Efficiency} = \frac{600 - 104}{328 + 461} = \cdot 45.$$

—*Hy. Dyer.*

305. Superheated Steam.

Superheated, *surcharged* (Hann and Gener), or *anhydrous* (Dr. Haycraft) steam or *stame* (Frost), is common steam heated away from contact with water. Theoretically it is more economical in use than common steam, as expansion takes place with less condensation, but, owing to its dryness and heat, the packing of the glands and the rods themselves are rapidly destroyed.

306. Condensation of Steam.

Steam may be condensed in

1. The vessel where its power is exerted	Savery, 1698 Newcomen, 1705
2. A separate vessel	Watt, 1769

Steam may be condensed by

1. Projecting a cold fluid against the vessel containing it ..	Savery
2. Injecting a cold fluid amongst it	Newcomen
3. Exposing it to large surfaces of cold fluids or solids ..	Watt Cartwright

4. The pressure of cold fluids against the vessel containing it } Perkins.
5. By the combination of two or more of these methods .. .. } Do.

—*Tredgold.*

307. Velocity of Fluids.

Flowing from atmosphere into vacuum.

W = weight per cubic ft. of the fluid in lbs.
p = atmospheric pressure in lbs. per sq. foot.
g = force of gravity = 32·2.
v = velocity in ft. per second.

$$v = \sqrt{\frac{2\,g\,p}{W}}.$$

Usually $p = 2116{\cdot}4$, then $2 \times 32{\cdot}2 \times 2116{\cdot}4 = 136{,}296{\cdot}16$, and approx.

$$v = \sqrt{\frac{136300}{W}},$$

or for water $v = 46{\cdot}5$, and air = 1338.

In all cases allowance must be made for friction, say

$$\text{approx. } v = \sqrt{\frac{100000}{W}}.$$

Velocity from one medium to another of given pressures P and p.

$$v = \sqrt{\frac{2\,g\,(P - p)}{W}}.$$

Steam of all pressures will rush into a perfect vacuum with a velocity of about 2000 ft. per second, no allowance being made for friction.

Steam of 60 lbs. pressure will rush into atmosphere about 1800 ft. per second.

308. Discharge of Steam through Pipes.

The velocity of discharge in pipes is in all cases proportional to the sectional area divided by the circumference, in round pipes this equals one fourth of the diameter, thus $\frac{d^2 \frac{\pi}{4}}{\pi d} = \frac{d}{4}$ and quantity discharged therefore varies as the diam.[3]

The pressure lost in discharging a fixed volume of steam varies inversely as the 4th power of the diameter of the orifice.

The steam pipe for an engine must be calculated as if constantly passing steam of the maximum velocity required to supply any part of the stroke. With single cylinder engines maximum velocity may be taken as 1·57 times the mean velocity; and with double cylinder engine, cranks at right angles, maximum = 1·11 times mean.

Single cylinder:

$$\begin{array}{l} \text{max.} = \pi s R \\ \text{mean} = 2 s R \end{array} \quad \therefore \text{max. exceeds mean by } \frac{\pi}{2} = 1{\cdot}57.$$

—*Box.*

309. Velocity of Steam in Pipes.

100 feet per second	—*Unwin.*
150 to 200 „	—‘*Practical Engineer*’.

310. Thickness of Steam Pipes.

Cast iron steam pressure pipes between 2 in. and 12 in. diam., and up to 70 lbs. boiler pressure,

$$d + 4 = t \text{ in } \tfrac{1}{16}\text{ths of an inch.}$$

For exhaust steam, suction, and ordinary low-pressure pipes of cast iron,

$$d + 10 = t \text{ in } \tfrac{1}{32}\text{nds of an inch.}$$

311. Expansion of Steam Pipes.

Steam pipes expand and contract about 1 in. in 50 ft., or ·02 ins. per ft., hence the necessity for inserting expansion pipes between each rigid connection.

312. Loss of Heat by Pipes.

A 4 in. steam pipe covered in hair felt and canvas loses about 120 units of heat per ft. run per hour at 60 lbs. per sq. in. pressure; bright copper pipe 350 units, rough black pipe 700 units. —*Box.*

313. Heating by Steam.

For heating by steam pipes, 10 sq. ft. window glass requires 1 sq. ft. pipe surface; 120 sq. ft. wall and ceiling also requires 1 sq. ft. pipe surface. 1 cub. ft. boiler space is sufficient for 2000 cub. ft. space in rooms. Each ft. run of 4 in. pipe will heat 200 cub. ft. air 1° F. per min.

SECTION X.

STEAM BOILERS.

314. Varieties of Boilers.

Early forms—spherical and cylindro-spherical of cast iron, afterwards all wrought iron.

Haystack or Balloon boiler—used formerly in Staffordshire: conical sides, dome top, small flat or hollow bottom.

Wagon boiler—used formerly in Lancashire: flat ends, cylindrical top, hollow curved sides and bottom, held by stays.

Egg-ended boiler—or cylindro-spherical set horizontally, with "flash" flues, afterwards made with internal flue, furnace always external.

Rastrick boiler—same as last but set vertically, one or more horizontal flues leading to main flue through boiler.

Cornish boiler—cylindrical, flat ended, with one flue tube containing furnace. London form shorter than original Cornish.

Lancashire boiler—similar to last, but with two flue tubes side by side containing furnaces.

Breeches-flued boiler—similar to last, but with flue tubes uniting into one at back of bridges.

Butterley boiler—similar to Cornish, but with flue tube enlarged at front end, and made elliptical to take wide furnace.

Galloway boiler—of Cornish or Lancashire type, but with taper water tubes placed diagonally across flue tubes.

French or Elephant boiler—formed of three horizontal cylindrical parts connected to each other by necks, two of these (heaters or bouilleurs) surrounded by brick flues.

Fairbairn boiler—same type as last, but with flue tube though each heater.

Marine boilers—formerly made flat-sided, or any shape to fit ship, stayed where required. Now made cylindrical, short, large diameter, one two or three furnace tubes, combustion chamber at back end in one or more divisions. 50 to 250 small tubes from combustion chamber to smoke box at front end.

Locomotive boilers—square furnace box at one end, water jacketed, connected with cylindrical boiler shell containing 200 to 300 small tubes for passage of gases to chimney.

Field boiler—vertical cylindrical, with furnace contained in inner cylinder, top of latter below water line and holding suspended in flame 50 to 60 small double tubes for circulation of water.

315. Production of Steam in Boilers.

Approximately 1 sq. ft. of grate surface, 1 sq. yd. of heating surface, 1 cub. yd. of boiler space will evaporate 1 cub. ft. of water in 1 hour, producing 1 N.H.P. each cub. inch of water forming 1 cub. ft. of steam at atmospheric pressure.

316. Horse Power of Boilers.

Nominal H. P. of Boiler = cub. ft. water evaporated from 60 F.° at any pressure in one hour = say 70,000 heat units.

Heat H. P. of Boiler is the amount of heat expressed in ft. lbs. transferred from the products of combustion into the water and steam per min. ÷ 33,000.

Mechanical H. P. of Boiler is the mechanical work done per min. by the water as it evaporates and expands into steam ÷ 33,000.

If P be absolute steam pressure in lbs. per sq. foot,

V = No. of cub. ft. steam produced per min.

then,

$$\frac{P\,V}{33{,}000} = \text{mechanical H. P. of boiler.}$$

In America a commonly accepted unit of horse power for steam boilers is the evaporation of 30 lbs. water per hour from and at 212 F.°

317. Horse-Power of Boilers from Dimensions.

S = heating surface in sq. yds.
g = grate surface in sq. ft.

$$\text{H.P.} = (\text{S} + g) \times \begin{cases} 1 \text{ for ordinary coal.} \\ \frac{3}{4} \text{ for good steam coal.} \\ \frac{1}{2} \text{ for best coal only.} \end{cases}$$

—*R. Armstrong.*

a = area in sq. ft. of water surface in boiler + horizontal sectional area of furnace tube in Cornish or Lancashire boiler.

	H.P. =			
Plain cylindrical boiler	$\frac{a}{6}$	..	..	$\sqrt{\text{S}g}$
Cornish or Lancashire boiler ..	$\frac{a}{6 \text{ to } 8}$	..	$\frac{3}{5}$ S	
Galloway boiler	$\frac{a}{4\cdot5}$			
Multitubular boiler	..	$\frac{g}{\cdot5 \text{ to } \cdot8}$	$\frac{1}{2}$ to $\frac{1}{3}$ S	$1\cdot8\sqrt{\text{S}g}$
Marine boiler (I.H.P.=5 N.H.P.)	..	..	..	$\cdot7\sqrt{\text{S}g}$

Another rule:—Nom. H. P. = $\frac{1}{8}$ length boiler in feet × diam. in feet.

The average number of cubic feet water evaporated per hour from cold feed with ordinary firing and good steam coal, is generally taken as the nominal H.P. of boiler, but two-thirds of a cubic foot is sufficient to develop 1 indicated H.P. in most steam-engines.

318. Chemical Composition of Fuels.

	Coal (mean 97 kinds).	Coke.	Wood (ord. state).	Peat (ord. state).
Carbon	·8040	·850	·408	·464
Hydrogen..	·0519	—	·042	·048
Oxygen	·0787	—	·334	·248
Nitrogen and Sulphur	·0246	—	—	—
Water	—	—	·200	·200
Ashes	·0408	·150	·016	·040
	Totals 1·0000			

319. Theoretical Units of Heat per lb. of Fuel.

		A
Coal (mean of 97)	13,006 ..	294
Coke	10,970 ..	269
Wood (dry)	6,582 ..	161
,, (ordinary)	5,265 ..	129
Charcoal	12,000 ..	294
Peat (dried)	8,736 ..	202

Column A gives cub. ft. air at 62 F° required per lb. of fuel—*Box on 'Heat.'*

320. Absolute Heating Power of Fuel.

p = absolute heating power of fuel in "calories"
C = percentage of carbon in fuel.

H = percentage of hydrogen in fuel.
W = „ chemically combined or hygroscopic water.

$$p = 80 \cdot 8\ C + 296 \cdot 3\ H - 6 \cdot 4\ W.$$

—*Industries.*

The *Calorific Power* (Dr. Percy) of a substance is the number of units of heat produced by the combustion of a unit of weight of the substance.

321. Units of Heat per lb. of Fuel (by Expt.)

Hydrogen burning to water	50,000
Carbon „ „ carbonic oxide	3,000
Do. „ „ „ acid	14,000
Carbonic oxide „ „ „ „	4,000
Welsh coal	8,500
Newcastle coal	8,000
Lancashire coal	7,500
Derbyshire coal	7,000
Wood (ordinary state)	5,000

322. Heating by Contact of Gases.

When difference of temperature is doubled, the rate of transmission is increased 2·35 times.

323. Rate of Transmission of Heat.

In locomotive boilers the rate of transmission per sq. ft. of heating surface is 11 thermal units per hour per degree Fahr. of difference in temperature.—*J. A. Longridge.*

In the boiler of s.s. *Meteor*, tested by Prof. Kennedy, 4769 thermal units per sq. ft. heating surface per hour were transmitted, or only 3 thermal units per hour per degree Fahr. of difference in temperature.—*D. Halpin.*

324. Loss of Strength in Copper Plates when Heated

At boiling point, 60 lbs. pressure, 307·5 F°,	= 10 per cent.
At 500 F°	50 „
At faint red heat, 1000 F°	75 „
At dull red heat, 1300 F°	100 „

325. Loss of Strength in Iron Plates when Heated.

At boiling point, 60 lbs. pressure, 307·5 F°, = *nil.*
If anything, the strength increases up to 320 F.°
At about 550 F° decrease begins to be perceptible.

At faint red heat, say 1000 F°	25 per cent.
At dull red heat, say 1300 F°	50 „

326. Comparative Value of Heating Surfaces.

Area of shell exposed to flame	= 1.
Horizontal area above flame	= 1.
Surface inclined towards flame	= $\frac{3}{4}$.
Vertical surface	= $\frac{1}{2}$.
Surface inclined from flame	= 0.
Horizontal surface below flame	= 0.

Internal cylindrical flues = $\frac{1}{2}$ circumference.
Small tubes = $\frac{2}{3}$ „
Shell of Cornish or Lancashire Boiler = $\frac{2}{3}$ to $\frac{3}{4}$ of lower half.

327. Heating Surface of Boilers.

Class.	Proportion of Heating Surface to Grate Surface.	Heating Surface to evaporate 1 cubic foot per hour.
Plain cylindrical	10–16 to 1	18 square feet
Cornish and Lancashire ..	15–25 to 1	14 „
Multitubular	30–40 to 1	9 „
Locomotive	60–80 to 1	6 „

A Lancashire boiler will evaporate 5 lbs. water per sq. ft. total heating surface per hour, or 2 cwt. ft. per sq. ft. fire-grate surface per hour, without pushing.

328. Products of Combustion.

100 lbs. coal { 80 lbs. carbon; 5 lbs. hydrogen; 15 lbs. sundry

960 lbs. air { $746\frac{2}{3}$ lbs. nitrogen; $213\frac{1}{3}$ lbs. oxygen

180 lbs. air { 140 lbs. nitrogen; 40 lbs. oxygen

$293\frac{1}{3}$ lbs. carbonic acid gas, say 2520 cub. ft.

45 lbs. water. say 946 cub. ft. steam.

15 lbs. ash.

$886\frac{2}{3}$ lbs. nitrogen, say 12000 cub. ft.

These figures assume perfect combustion and no losses.

329. Air Required to Burn Fuel.

For the complete combustion of 1 lb. of fuel, the lbs. air theoretically necessary = $\cdot 117$ times the percentage of carbon + $\cdot 35$ times the percentage of free hydrogen.

e. g. carbon, 70 per cent.; hydrogen, 3 per cent.

$$\cdot 117 \times 70 + \cdot 35 \times 3 = 9\cdot 24 \text{ lbs. air per lb. fuel.}$$

—*Industries.*

100 cub. ins. atmospheric air at 60° F. and 30″ bar. = 31 grains; $\therefore$ 1 cub. ft. = $\cdot 093$ lbs.; 12 cub. ft. oxygen weigh 1 lb., and to obtain 1 lb. oxygen, 5 lbs. air must pass through fire = 60 cub. ft.

2 to 3 lbs. oxygen required to burn 1 lb. of coal, or, assuming only $\frac{2}{3}$rds. effective, 180 to 270 cub. ft. will be required.

In general the quantity of air provided should be double the minimum theoretical quantity.

Air and smoke together equal about 2000 cub. ft. per cubic foot of water evaporated, temperature say 800° F.

Maximum economical draught for boilers = pressure due to ½ inch head of water, causing consumption of 36 lbs. coal per hour per sq. ft. fire-grate, and requiring 24 lbs. air per lb. coal.

330. Heat in Flue.

With Cornish boiler, temperature of escaping gases at base of flue may be as low as 500° F.

With short multitubular boiler, as high as 1200° F.

A pyrometer indicating up to 1000° F. was placed in the flue at end of a multitubular boiler of locomotive type, containing tubes 7 ft. × 2¾ in., when the pointer went beyond the range of the instrument = say 1100° F.

The temperature is generally ascertained by hanging strips of metal foil, on an iron wire, across the flue, and noting which are melted by the heat, viz.: copper 2000°, aluminium 1800°, zinc 750°, lead 630°, tin 440°.

331. Brick Chimney-shafts.

The bond usually adopted is 1 course of headers to 4 of stretchers.

Up to 120 feet high the top length is generally one brick thick; above that height, top length 1½ brick thick.

Height of any length of uniform section should not exceed 90 feet, and should be less in thin sections.

45 feet is an ordinary height for two steam boilers, but in some towns, as Manchester and Leeds, the minimum height allowed is 90 feet.

A minimum wind pressure of 55 lbs. per sq. ft. must be allowed for in calculating stability.

Round chimneys should not exceed 25 times internal diameter in height.

332. Size of Factory Chimney for Boilers.

W = weight of coal burnt in lbs. per hour.
A = area of chimney in square feet at top.
H = height of chimney in feet.
c = cub. ft. evaporated per hour.

$$A = \frac{W}{14\sqrt{H}}, \qquad W = 14\,A\sqrt{H}, \qquad H = \left(\frac{W}{14\,A}\right)^2$$

$$\text{or } A = \frac{1{\cdot}5\,c}{\sqrt{H}}.$$

Chimney for single boiler, area = $\frac{1}{8}$ fire-grate.
Do. under 150 feet high for more than one ,, = $\frac{1}{10}$,,
Do. over 150 feet high do. ,, = $\frac{1}{15}$,,

$$\text{Area of chimney in square inches} = \frac{\text{lbs. coal per hour} \times 12}{\sqrt{\text{height feet}}}.$$

—*Bourne.*

Area of chimney usually $\frac{1}{10}$ area of fire-grate and 40 feet high.—*Scott Russell.*

20 square inches area per N.H.P. of engine.
Height about 20 times internal diameter.
Flues $\frac{1}{5}$ area of fire-grate, diminishing to $\frac{1}{10}$ at chimney.
Height of chimney = 45 feet.

$$\text{Area of chimney} = \frac{\text{area fire-grate}}{\sqrt{\text{height}} \times 1{\cdot}58}. \qquad \text{—\textit{Elswick}.}$$

Do. = $1\frac{1}{2}$ sq. ins. per lb. of coal per hour.—*Murray.*

$$\text{Velocity of gases} = 8\sqrt{\text{motive height}} = 8\sqrt{h\left(\frac{T-t}{459+T}\right)}.$$

$$\text{Do. practically} = 6\sqrt{\frac{h}{1+\frac{T-t}{500}}}$$

—*Tredgold.*

Ordinary velocity of gases in chimney shaft = $2 \cdot 4\sqrt{H}$.

Most economical temperature of escaping gases = 600° Fahr.

At this temperature the volume of air entering furnace is doubled on exit.

A cubic foot of water requires 10 lbs. coal to evaporate it; 10 lbs. coal require 210 lbs. air for complete combustion, = say 2750 cubic feet.

The force of the draught in a chimney stack is the deficiency of weight of the column of rarefied air in the chimney compared with a similar column of the external air.

$$\text{Approx. H.P. of round chimney} = \frac{d\ \text{ins.}^3}{300}.$$

Funnel for marine engine = 3 to 5 sq. in. per I.H.P.

333. Metropolitan Board of Works * Rules for Furnace Chimney Shafts.

The width of a shaft at the base, if square on plan, must be at least one-tenth, and if circular on plan at least one-twelfth of the total height.

A shaft must have a batter of 2½ inches in every 10 feet of height.

* Now the London County Council.

The brickwork must be at least 8½ inches thick at the top of the shaft and for 20 feet below, and must be increased 4½ inches in thickness for every 20 feet of additional height, measured downwards.

No portion of the enclosures of a shaft is permitted to be constructed of fire-brick, and any fire-brick lining to be used must be in addition to the thickness of, and independent of, the brickwork.

No cornice or other projection is allowed to project more than the thickness of the brickwork at the top of the shaft.

334. Coal burnt per square foot of Fire-grate.

	lbs. per hour.
Cornish boilers for pumping engines ..	4 to 10
„ and others for factory uses ..	10 „ 15
Marine boilers, ordinary rates	15 „ 20
Boilers with strong chimney draught ..	20 „ 30
Locomotives	60 „ 120

335. Loss of Heat in Boilers.

Assuming that it requires 10 lbs. of coal to evaporate 1 cubic foot of water from 60° into steam at 60 lbs. per square inch gauge pressure, the loss of heat may be shown, as follows, to be nearly 50 per cent. :—

Total heat of combustion in 1 lb. of coal in
British thermal units = say 13,000.
13,000 units per lb. × 10 lbs. coal .. = 130,000

Steam at 60 lbs. pressure has a total heat of 1207 units, 1207 − 60° temp. of feed-water = 1147 units per lb. of water. 1 cub. foot water = 62·5 lbs. 62·5 × 1147	=	71,687
Loss in chimney, 24 lbs. air, required to burn 1 lb. coal. 24 × 10 = 240 lbs. to burn 10 lbs. coal. Specific heat of air = ·2374, temperature of escaping gases = 600°. 240 × ·2374 × 600	=	34,185
Loss in hot ashes, fuel dropped through, &c., say 7 per cent. of total heat	=	9,100
Loss by radiation and conduction, say 7 per cent.	=	9,100
Loss by imperfect combustion, say 4½ per cent.	=	5,850
		129,922

336. Heat in Boiler Furnaces.

1. Temperature of furnace, say about 2500° F.
2. „ of escaping gases, say 600 to 1200° F.
3. „ steam and water in boiler, say 300° F.
4. „ water in condenser, say 100° F.

Difference between (1) and (2) is absorbed by the water in raising its temperature, by the steam as latent heat, and by the air entering furnace in excess of quantity required for combustion.

Difference between (2) and (3) is utilised in creating draught; 600° is the most economical temperature of escaping gases, as it allows sufficient difference of temperature for rapid passage of heat to water, and the density is sufficiently reduced to give rapid ascending current in chimney shaft.

Difference between (3) and (4) is utilised in the engine.

The difference of temperature or quantity of sensible heat does not by itself represent the comparative efficiency.

337. Evaporative Value at Different Temperatures.

In stating the evaporative power of a boiler it is usual to express it in terms of feed-water evaporated from 212°.

t = actual temperature of feed-water.
T = total heat of steam under given pressure.
c = cubic foot of water evaporated from $t°$.
C = „ „ „ from 212° by same quantity of heat.
$T - t$ = heat imparted.

$$C = c\,\frac{T - t}{966 \cdot 1}.$$

338. Experiments on Evaporation in Boilers.

Class.	Size.	Lbs. Water per lb. Coal.	Lbs. Coal per cub. foot Water.
Cornish	20 H.P.	6·764	9·212
Lancashire ..	25 „	7·547	8·256
Galloway ..	35 „	9·5	6·579
Field	..	10·9	5·734

In a case where an engine was allowed to get into bad condition, with considerable leakage past valves and pistons, it appeared as if 3 lbs. of water were evaporated by 1 lb. of coal, or 21 lbs. of coal were required to evaporate 1 cubic foot of water. This was on the assumption that the engine required only the normal amount of steam.

339. Feed-water Required for Boilers.

Gallons feed-water required per hour = say nom. H.P. of boiler × 10 to allow for losses, or I.H.P. of engine × 5 for ordinary work or × 6 for max. work.

Boilers supplying engines pumping water against accumulator pressure and working intermittently require about $2\frac{1}{2}$ gallons per working hour per effective H.P. on the average of the year.

340. Duty of Engines.

s = Standard of comparison in lbs: =

Cwt. any coal	112 lbs.
Bushel Welsh coal ..	94 „
„ Newcastle coal	84 „

w = lbs. wt. coal burnt per I.H.P. per hour.

n = No. of cwts. or bushels burnt per hour.

$$\text{Duty in ft.-lbs. per standard} = \frac{\text{I.H.P.} \times 33{,}000 \times 60}{n}.$$

$$\text{Do.} \quad = \frac{33{,}000 \times 60 \times s}{w}$$

$$\text{Duty in million ft.-lbs. per cwt.} = \frac{221 \cdot 76}{w}.$$

Cornish duty:

g = gallons of water pumped per hour.

f = feet lift of water pumped.

n = bushels of 94 lbs. coal.

$$\text{Duty} = \frac{10\,g\,f}{n}.$$

341. Duty of Engines Compared with Coal Used.

C = Consumption of coal per I.H.P. in lbs.

D = Duty in million lbs. raised 1 ft. high by 1 cwt. of coals.

C.	D.	C.	D.
1	221·760	7	31·680
2	110·880	8	27·720
3	73·920	9	24·640
4	55·440	10	22·176
5	44·352	11	20·115
6	36·960	12	18·480

Assuming 1 lb. coal to contain 13,000 units of heat, and the duty of a Cornish pumping engine $107\frac{1}{2}$ million ft.-lbs. per bushel (94 lbs.), only $\frac{1}{9}$th of the theoretical value is obtained.

342. Consumption of Fuel.

Boilers may be made to do 70 per cent. more work if consumption of fuel can be doubled.

In ordinary cases large boilers utilise 8000 units of heat per lb. of coal.

Theoretically, $\frac{1}{6}$ lb. coal per hour = 1 H.P., "but the best coal is not all carbon, and is usually rated as yielding 10 millions of foot pounds of work per pound of coal consumed, of which more than one-fourth is lost in the best boilers."

343. Effect of Supervision of Boilers.

Men being aware the work was measured: 100 hours, evaporation (average from and at 212° F.) = 9·7 lbs. water per lb. fuel.

Men not being aware the work was measured: 220 hours, evaporation (average from and at 212° F.) = 9·3 lbs. water per lb. fuel.

Difference = $4\frac{1}{2}$ per cent. in favour of supervision.

—*E. Bennis.*

344. Boiler Furnaces.

With bituminous fuel the layer in the furnace should be about 6 inches thick, and should never exceed 12 inches. Thin firing is more economical, but requires more careful stoking. Fresh fuel should be put in front of the fire and the red-hot fuel pushed back, or should be spread thinly over the surface after the hollows are filled up. With

coke or hard coal the fire may be thicker, especially if a blast be used.

Small coal, or slack, has about half the evaporative power of coal or coke.

345. To Calculate Size of Boiler.

Say Cornish boiler for high-pressure engine:

d = diameter of cylinder in feet.
s = stroke in feet.
R = revolutions per minute.
r = ratio of cut-off.
p = boiler pressure, lbs. per square inch by gauge.
n = number of cylinders.
S = cubic feet steam required per hour, allowing 25 per cent. for contingencies.

$$S = 1 \cdot 25\, d^2 \frac{\pi}{4}\, s\, r\, 2\, n\, R\, 60 = \text{say } 120\, d^2 s\, r\, n\, R.$$

v = relative volume of steam at p pressure.
W = weight of water to be evaporated in lbs. per hour.

$$W = \frac{62 \cdot 5\, S}{v}.$$

c = combustion of coal in lbs. per square foot fire-grate per hour, say for Cornish boiler = 12 lbs.
e = evaporation in lbs. of water from 60° Fahr. per lb. of coal, say for Cornish boiler = 7 lbs.
$c \times e$ = lbs. water evaporated per square foot fire-grate per hour.
A = area of fire-grate in square feet.

$$A = \frac{W}{c\, e}.$$

l = length of fire-grate in feet, say 4·5 to 5·5, but must not exceed twice the width.

w = width of fire-grate in feet.

$$w = \frac{A}{l} + \cdot 166.$$

D = diameter of boiler shell = $1 \cdot 75\, w$.
L = length of „ = 4 D.

When w exceeds $3 \cdot 25$, make two Cornish boilers or one Lancashire.

For latter, $D = 2\frac{1}{2}\, w$ (w being width of *one* furnace).

346. Cornish Boiler.

Approximate heating surface in sq. yds. of unit value,

$$= \frac{L \frac{\pi}{2} (d + \frac{2}{3} D)}{9} - \text{space occupied by seatings.}$$

$$= \text{say } \cdot 17\, L\, (d + \tfrac{2}{3} D).$$

Total capacity in cubic feet,

$$= L \frac{\pi}{4} (D^2 - d^2) \quad = \cdot 8\, L\, (D^2 - d^2).$$

Approximate space for steam, remainder water,

$$= \frac{L\ D^2 \frac{\pi}{4}}{6} = \cdot 13\, L\, D^2.$$

Minimum steam space = quantity required for 10 revolutions of engine. Water space 5 to 10 cub. ft. per N.H.P., and 5 ft. super. water surface per N.H.P.

347. Comparison of Cornish Boiler with I.H.P. of Engine.

I.H.P. of engine = effective heating surface of boiler in sq. yds. of unit value.

$\frac{1}{2}$ I.H.P. of engine = cubic yards total capacity of boiler, of which $\frac{1}{4}$ = steam, $\frac{3}{4}$ = water.

$\frac{2}{3}$ I.H.P. of engine = area of fire-grate in sq. ft.

Steam receiver may be attached to boiler, maximum size equal in diam. to flue tube, length = twice diam.

Steam dome to allow supply pipe to take dry steam, may equal $\frac{2}{3}$ diam. of flue tube, with height = diam. of flue.

348. Fire-Bars

Should not exceed 3 feet in length. Ordinary furnaces should not exceed 6 feet in length, the bars in two lengths. Dead-plate should be 9 to 15 inches wide. Fire-bars say 3 feet long, 3 inches deep in middle, $\frac{3}{4}$ inch thick at top, tapered to $\frac{3}{8}$ inch thick at bottom; bevelled one end to rest on dead-plate, to allow for expansion, and notched at other to rest on wrought iron bearer: if notched both ends, there should be not less than 1-inch play. Chipping faces or distance pieces on bars should be made at both ends and middle. Air spaces between bars $\frac{3}{8}$ inch to $\frac{5}{8}$ inch, usually $\frac{1}{2}$ inch. The fire-grate should incline downwards towards the back, $\frac{3}{4}$ inch to 1 inch per foot. Passage above bridge = one-sixth area of grate. Perforations in furnace door, $\frac{3}{8}$ inch to $\frac{1}{2}$ inch diameter; total area, from 2 to 5 square inches per square foot fire-grate.

349. Boiler Seatings.

With old form of wheel draft the boiler was set on a mid-feather: this is a bad arrangement. Should be set on fireclay blocks forming side walls, the resting surfaces not wider than one-twentieth diameter of boiler, or $\frac{3}{4}$ inch per foot diameter.

Flues should be large enough for a man to pass entirely

round, area should be kept as uniform as possible, corners rounded, and angles filled up.

Externally fired boilers are frequently set with flash flues, i. e. the gases pass directly from furnace, over the bridge, and along bottom of boiler, to chimney. Boilers should be set with a fall of about 1 in 200, or $\frac{1}{16}$ inch per foot, towards front.

350. Size of Manholes in Boilers.

12 in. × 8 in. can be entered by small boy.
13 „ 9 „ „ „ lad.
14 „ 10 „ „ „ average man.
15 „ 12 „ „ „ stout man.

351. Boiler Tubes.

Class of Boiler.	Ratio, Length to Diameter.	Ratio, Tube Area to Grate Area.
Multitubular boilers, with chimney draught	24 to 1	1 to 7
Locomotive boilers	120 to 1	1 to 4
Small marine boilers, with high-pressure engines	33 to 1	1 to 6
Large marine boilers, with condensing engines	20 to 1	1 to 3

1 square foot of fire-box is equal to 3 square feet tube surface: $\frac{1}{2}$ diameter should be left between the tubes for circulation and escape of steam.

Heating surface of small tubes = $\frac{2}{3}$ of circumference, of furnace tubes = $\frac{1}{2}$ circumference.

In multitubular boilers the stay-tubes should be spaced so as to support the whole plate, irrespective of support from other tubes.

352. Water-gauge Glass.

Lowest sight level of water-gauge glass should be 3 in. to 4 in. above furnace crown or highest point of boiler exposed to flame.

Water heated from its point of maximum density (39° F.) to boiling point (212° F.) expands about one twenty-third of its volume.

353. Taper of Plugs for Boiler-cocks.

For pressures up to 30 lbs. per square inch, a taper of 1 in 8 on each side is found to work well; but for pressures of about 100 lbs., a taper of 1 in 12 is necessary to insure tightness; say 1 in 10 minimum for pressure of 60 lbs.

354. Blow and Scum.

The sediment in a boiler, and the floating impurities, should be blown out after a short period of rest, say during meal times.

When laying off for cleaning, the water should not be all blown out, or the scale will harden excessively and be more difficult to remove.

355. Boiler Scale.

Increased quantity of fuel required to evaporate water:—

Scale	$\frac{1}{16}$	inch thick	=	15	per cent.
"	$\frac{1}{4}$	" "	=	60	"
"	$\frac{1}{2}$	" "	=	150	"

—*Prof. J. G. Rogers.*

If the feed water contains 30 grains of solid matter per

gallon, a 20 H.P. boiler will deposit half a pound per hour.

Order of deposition of impurities as water becomes concentrated:—

1. Carbonate of lime.
2. Sulphate of lime.
3. Salts of iron, as bases or oxides, and some of these of magnesia.
4. The silica or alumina, usually with more or less of organic matter.
5. Common salt.—*M. Cousté.*

Soda (carbonate) is the best natural de-incrustant.

356. Hardness of Water.

When a water contains in solution one part by weight of lime, or other equivalent hardening salt, in 100,000 parts of water, it is said to possess 1° of hardness.

Water of less than 6° of hardness dissolves lead to an extent dangerous to health if used for domestic purposes.

Parts carbonate lime per 100,000 water × $\frac{7}{10}$ = grains per imperial gallon, or degrees of hardness on Clark's scale. Carbonate of lime produces temporary hardness in water, sulphate of lime produces permanent hardness.

357. Sea-water.

	Parts per 1000.
Proportion of salt in water of open sea	32 to 38
„ „ „ Red Sea	43
„ „ „ Mediterranean	38
„ „ „ British Channel	35·5
„ „ „ Arctic Ocean	28·5
„ „ „ Black Sea	21
„ „ „ Baltic	6·6

—*Ure*

Average specific gravity of sea water at 60° F., pure distilled water being 1 :—

Faraday	1·027	Marcet	1·0277
Mallett	1·0278	Fitzroy	1·027

Salts contained in sea water—

	Parts per 1000.
Chloride of sodium	25
Muriate of magnesia	3
Sulphate of magnesia	2
Sulphate of lime	1
Others	1
TOTAL	32

—*Faraday.*

Weight of one cubic foot about 64·14 lbs.

358. Safety Valves for Boilers

Should always be in duplicate.

Area in sq. ins. for each = ·004 to ·006 area of fire-grate surface, usually ·025 sq. ins. per sq. ft. heating surface, or ·5 sq. ins. per sq. ft. grate surface, irrespective of working pressure.

Actual lift of valve $= \frac{2\,d}{p}$ or $\frac{d}{36}$, but freedom must be allowed for a lift of $\frac{1}{4}\,d$.

Valves should be flat faced to prevent sticking, face $\frac{1}{8}$ inch to $\frac{1}{12}$ inch wide.

In estimating the blow-off pressure, add $\frac{1}{16}$ inch to the actual diam. inside face of seat.

When diameter would exceed 4 inches, two or more valves must be provided.

A = effective area of heating surface, sq. ft.
H = boiler H.P. (1 cub. ft. per hour evap. from 60°).
G = grate surface, sq. ft.

$$A = 8\,(H + 2\cdot 5\,\sqrt{H}), \quad G = \frac{H + 2\cdot 5\,\sqrt{H}}{2}, \quad G = \frac{A}{16}.$$

$$\text{Diam. of safety valve, ins.} = \sqrt{\frac{A}{27}}$$ —*Box.*

$$\text{Diam. of safety valve, ins.} = \sqrt{\frac{\text{grate surface, sq. ft.}}{\text{gauge pressure, lbs.}}}$$

—*Tredgold.*

Twin safety valves, each—

$$\text{Area} = 18\,\frac{\text{grate surface, sq. ft.}}{\text{abs. press., lbs. sq. in.}}$$

$$\text{or area} = \frac{0\cdot 6\ \text{heating surface, sq. ft.}}{\text{abs. press., lbs. sq. in.}}$$

Or one as above fitted as an easing valve, and one as follows loaded to 1 lb. per sq. in. less—

$$\text{Area} = 4\,\frac{\text{grate surface, sq. ft.}}{\text{abs. press., lbs. sq. in.}} + \text{area of guides of valve;}$$

$$\text{or area} = \frac{0\cdot 133\ \text{heating surface, sq. ft.}}{\text{abs. press, lbs. sq. in.}} + \text{ditto.}$$

If the heating surface exceeds 30 sq. ft. per square foot of fire-grate, safety valve must be determined from heating surface. —*Inst. Eng., Scot.*

359. Board of Trade Rules for Safety Valves.

Boiler Pressure.	Area per sq. ft. of Fire-grate.	Boiler Pressure.	Area per sq. ft. of Fire-grate.
15	1·25	70	·441
30	·833	80	·394
40	·681	90	·357
50	·576	100	·326
60	·500	120	·277

360. To Calculate Safety-valve Leverage.

a = area of valve in square inches.
p = gauge pressure in lbs. per square inch.
W = weight on end of lever in lbs.
w = weight of lever in lbs.
w' = weight of valve and stud in lbs.
L = distance between weight and fulcrum in inches.
g = do. centre of gravity of lever and do.
l = do. valve centre and do.

$$W = \left[p\,a - \left(w' + \frac{w\,g}{l}\right)\right]\frac{l}{L}. \qquad L = \left[p\,a - \left(w' + \frac{w\,g}{l}\right)\right]\frac{l}{W}.$$

$$p = \frac{\dfrac{w\,g + W\,L}{l} + w'}{a}. \qquad a = \frac{\dfrac{w\,g + W\,L}{l} + w'}{p}.$$

The lever safety valve was invented by Papin.

361. Notes on Spiral Springs.

Effective number of coils = generally 2 less than apparent number, owing to flattening at ends for bases.

Stroke = effective number of coils × compression or extension of each coil.

Minimum pitch of spiral = diameter of steel in inches + twice compression of one coil under full load, but coils may lie close when spring is for tension only.

Diameter of coil = say 8 times diameter of steel.

Working load may stretch each coil = $\frac{1}{2}$ diameter of steel composing spring.

To increase stroke, add to the number of coils.

Spring in tension is more accurate for exact work than one in compression.

Best form of section is circular, but square form is stronger, as 10 to 7.

Two or more springs may be used, one within the other.

362. Spiral Springs.

Formula for strength and deflection.

E = Compresssion or extension of one coil in inches.
D = Diameter of coil in inches from centre to centre.
d = Diameter or side of square of steel composing spring in $\frac{1}{16}$ths of an inch.
W = Weight applied in lbs.
c = a constant found by experiment, which may be taken as 22 for round steel and 30 for square steel.

$$E = \frac{D^3 W}{d^4 c}.$$

363. Spiral Springs, Rankine's Formula.

d = diameter of wire in inches.
c = coefficient of transverse elasticity of wire, say 10,500,000 to 12,000,000 for charcoal iron wire and steel.
r = radius to centre of wire in coil.
n = effective number of coils.
f = greatest safe shearing stress, say 30,000.
W = any load not exceeding greatest safe load.
v = corresponding extension or compression.
W′ = greatest safe steady load.
v' = greatest safe steady extension or compression.

$\frac{W}{2}$ = greatest safe sudden load.

$$\frac{W}{v} = \frac{c\,d^4}{64\,n\,r^3}. \qquad W' = \frac{\cdot 196\,f\,d^3}{r}. \qquad v' = \frac{12 \cdot 566\,n\,f\,r^2}{c\,d}.$$

Ratio $\frac{W}{v}$ should be ascertained by direct experiment.

—*Rankine's 'Machinery and Millwork.'*

In two series of experiments analysed by the author, the ratio W to v was greater by 12 and 30 per cent. respectively than given by the formula, the former in tension, the latter in compression.

364. Spiral Springs for Safety Valves.

a = Area of valve in sq. in.
c = 11,000 for square steel = 8000 for round steel.
D = Diameter of spring, ins. centre to centre of coil.
E = Compression or extension of one coil, ins.
p = Pressure lbs. per sq. in. on valve.
d = Diameter of steel or side of square in inches.
d_1 = „ „ „ in sixteenths.

$$d = \sqrt[3]{\frac{a\,p\,D}{C}}.$$

Let $E = \frac{D^3\,a\,p}{30\,d_1^4}$ for square steel

then $E = \frac{D^3\,a\,p}{22 \cdot 8\,d_1^4}$ for round steel.

—*'Practical Engineer.'*

365. Initial Compression of Springs for Safety Valves

May be 40 times the lift of the valve, and assuming the lift of all sizes to be $\frac{1}{10}$ inch, the initial compression will then be 4 inches.

Or may be 1·11 diam. of valve in inches.

Or by another rule :

$$\text{Initial compression} = \frac{80 \times d.\text{ of valve ins.}}{p.\text{ lbs. sq. in.}}.$$

If lever is used, then movement of lever must be taken in calculating spring, instead of lift of valve.

366. Spring-Balance Safety Valves.

The levers are generally proportioned so that 1 lb. pressure per sq. in. on the valve gives 1 lb. pull on the spring, but the spring is tightened up to the blowing-off pressure, so that the actual indication is only shown when the blowing-off pressure is exceeded. The length of lever from centre of valve to fulcrum is made equal to diameter of valve, and the length from fulcrum to centre of attachment of spring is made equal to the diameter of valve multiplied by its area, all inches. The total length may be increased if the same proportion of its subdivisions be retained.

367. To Calculate Springs for Safety Valves.

Given boiler pressure and grate surface, find—

1. Diam. of valve.
2. Load required.
3. Lift of valve.

4. Initial compression of spring.
5. Assume diameter of coils.
6. Find diameter of steel.
7. Compression of each coil.
8. Effective number of coils.
9. Pitch of spiral.
10. Effective length of spring.
11. Total length.

368. Factor of Safety, Steam Boilers.

Test pressure = $\frac{1}{3}$ ultimate strength.

Working pressure, if under periodical inspection, = $\frac{1}{5}$ do.

Working pressure, if not under independent inspection, = $\frac{1}{6}$ do.

In estimating ultimate strength, ample allowance to be made for defects in design or workmanship.

369. Testing Boilers.

Government Yards.—New boilers to be tested to three times their working pressure. Boilers in use not to be worked more than 300 hours without being laid off for examination. To be tested periodically to twice their working pressure.

Best Private Practice.—New boilers to be tested to twice their working pressure. Boilers in use not to be worked more than 1000 hours without being laid off for examination. To be tested after repairs to $1\frac{1}{2}$ times their working pressure. If working with impure water, to be examined after 500 hours.

370. Riveting for Boilers.

In iron :—

Ring seams to be single riveted, longitudinal seams double riveted.

For equal area of plate and rivet, the linear pitch in single riveted joints and diagonal pitch in double riveted joints should be

$$= \frac{\text{sectional area of one rivet}}{\text{thickness of plate}} + \text{diam. of rivet.}$$

For same conditions, the linear pitch in double riveted joints should be

$$= \frac{\text{2 sectional area one rivet}}{\text{thickness of plate}} + \text{diam. of rivet,}$$

but is generally made about one-sixth less than this, to avoid straining in caulking. Double riveting should always be zig-zag.

For rivets in double shear, take 1·75 times above areas.

371. Ultimate Strength of Boiler-shell.

Longitudinal strength:

$$p\,d\,l = 2\,t\,l\,c \;\therefore\; p\,d = 2\,t\,c,$$

$$p = \frac{2\,t\,c}{d}, \qquad t = \frac{pd}{2\,c}.$$

Transverse strength:

$$p\,\frac{d^2\,\pi}{4} = \pi\,(t + d)\,t\,c,$$

divide by $\frac{\pi}{d}$, then

$$p\,\frac{d}{4} = \left(\frac{t}{d} + 1\right) t\,c;$$

but $\frac{t}{d}$ will rarely exceed $\cdot 01$, and may therefore be omitted.

$$\therefore \ p \frac{d}{4} = t\, c, \quad p = \frac{4\, t\, c}{d}, \quad t = \frac{p\, d}{4\, c},$$

or the transverse strength is double the longitudinal.

372. Collapsing Pressure of Boiler-tubes.

Length not exceeding 15 diameters.

Cylindrical:

$$p = 33\cdot 61 \times \frac{(100\, k)^{2\cdot 19}}{\mathrm{L}\, d};$$

—*Fairbairn.*

or $\log p = 1\cdot 5265 + 2\cdot 19 \log 100\, k - \log \mathrm{L}\, d$;
or approximately,

$$p = \frac{800{,}000\, t^2}{\mathrm{L}\, d}.$$

Elliptical:

$$p = \frac{800{,}000\, t^2}{\mathrm{L}\, (2\, r)}, \quad r = \text{radius of flatter curve},$$

$$p = \frac{800{,}000\, t^2}{\mathrm{L}} \times \frac{2\, \mathrm{D}^2}{d}.$$

D d are the two diameters in inches, L the length in feet.

373. Boilers.—Comparison between Bursting and Collapsing Pressures.

P = internal or bursting pressure in lbs. per square inch.
p = external or collapsing " " "
c = ultimate strength of single riveted joint = say 30,000 lbs.

l = length of unsupported cylindrical tube in feet.
D = diameter of boiler in inches.
d = „ tube „
T = thickness of shell plate in inches.
t = „ tube „ „
R = ratio of tube diameter to shell diameter $= \frac{d}{D}$.

$$P = \frac{2\,T\,c}{D} = \frac{60{,}000\,T}{D}.$$

$$p = \frac{800{,}000\,t^2}{l\,d}.$$

$$\frac{P}{p} = \frac{60{,}000\,T\,l\,d}{800{,}000\,t^2\,D} = \frac{T\,l\,R}{13\cdot 3\,t^2}.$$

$$\therefore \text{ When } P = p, \text{ then } l = \frac{13\cdot 3\,t^2}{R\,T}.$$

374. Collapsing Pressures of Flues.

$L' \times D''$	$\frac{1}{4}''$	$\frac{5}{16}''$	$\frac{3}{8}''$	$\frac{7}{16}''$	$\frac{1}{2}''$	
400 ..	97	158	235	329	441	lbs. per sq. in.
500 ..	77	126	188	263	353	„ „
600 ..	65	105	157	219	294	„ „
700 ..	55	90	134	188	252	„ „
800 ..	48	79	117	164	229	„ „
900 ..	43	70	104	146	196	„ „
1000 ..	38	63	94	131	176	„ „

—*Munro.*

375. Helical Joints for Boilers.

Ratio of strength to longitudinal joint.

$$= \frac{2}{\sqrt{(3\cos^2\phi + 1)}}$$

ϕ = angle of inclination from longitudinal direction.

376. Locomotive Boiler.

Pressure 130 to 150 lbs. per sq. in.

Feet of heating surface = inches diam. piston $^2 \times 4$.

Heating surface of firebox = $\frac{1}{12}$ to $\frac{1}{10}$ of total.

Sq. ft. area fire-grate = ins. diam. piston − 1.

Tubes 10 to 12 ft. long, $1\frac{5}{8}$ in. to $1\frac{3}{4}$ in. internal diam. 11 to 13 W.G., $\frac{5}{8}$ in. clearance between.

Shell plates $\frac{3}{8}$ in. to $\frac{5}{8}$ in., $t = \frac{p\,d}{960}$ when t = thickness sixteenths, p = press. lbs. sq. in., d = diam. ins.

Diameter of shell = diam. piston × 3.

Smoke box tube plate = $1\frac{1}{2}\,t$.

Side plates, outer casing, firebox = $t + \frac{1}{16}$ in.

Throat plate and back plate = $t + \frac{1}{8}$ in.

Firedoor = 18 in. × 12 in. Inner casing of firebox, copper.

Inner tube plate, upper part = $\frac{1}{4}$ in. thicker than lower part.

Holes in tube plates = $\frac{1}{8}$ in. smaller at firebox end and $\frac{1}{8}$ larger at smokebox end than mean outside diam. of tubes.

Stay bolts, 4 in. pitch, $\frac{3}{4}$ in. over thread with $\frac{3}{8}$ in. plate, $\frac{7}{8}$ in. with $\frac{1}{2}$ in. plate, $\frac{15}{16}$ in. with $\frac{5}{8}$ in. plate.

Girder stays (8) in 2 plates 5 in. × $\frac{5}{8}$ in. to 6 in. × $\frac{3}{4}$ in., 2 in. clearance above crown, secured by stay bolts same size as in sides of firebox.

Steam dome = $\frac{1}{2}$ diam. of barrel, height = diam., thickness same as shell plates, top $\frac{3}{4}$ in. to $\frac{7}{8}$ in. thick and $7\frac{1}{2}$ in. high.

Manholes, 16 in. diam.

Twin safety valves, each with clear passage of area = $\frac{1}{12000}$ of heating surface,

$\therefore$ diam. ins. = $\cdot 08 \sqrt{\text{heating surface, sq. ft.}}$

Chimney, 13 ft. 3 ins. from rail level to top, smallest diam. ins. = 4 $\sqrt{}$ area grate, sq. ft.

Steam pipe = $\frac{1}{16}$ area of piston.

Air space through bars = $\frac{1}{5}$ of grate area.

Fire-bars, centre depth = $\frac{1}{8}$ length; thickness, top = $\frac{1}{50}$ length; thickness, bottom = $\frac{1}{100}$ length; end depth = $\frac{3}{5}$ middle depth. —'*Railway Press.*'

SECTION XI.

THE STEAM ENGINE.

377. Horse-Power.

Actual H.P. = 33,000 ft.-lbs. per min. in all calculations, but the actual work of a horse is about 22,000 ft.-lbs. per minute.

Watt's nominal H.P. for low pressure engine (pressure 7 lbs. per sq. in.* above atmosphere),

$$= \text{area sq. ins.} \times 7 \times 128 \times \sqrt[3]{\text{stroke ft.}} \div 33{,}000$$
$$= d \text{ in ins.}^2 \times \sqrt[3]{\text{stroke ft.}} \div 47.$$

Boulton and Watt's N.H.P. for high pressure engines,

$$= d^2 \div 14 \ (\therefore\ 11 \text{ sq. ins. piston per N.H.P.})$$

Do. do. for condensing engines,

$$= d^2 \div 28 \ (\therefore\ 22 \text{ sq. ins. piston per N.H.P.})$$

Bourne's N.H.P. three times that of Watt, viz. for a pressure of 21 lbs. above atmosphere.

* In all machinery actuated by fluid pressure, the square inch, which is the standard unit, introduces a needless complication. James Watt lost a good opportunity in not establishing the circular inch as the standard.

Circ. ins. × ·7854 = sq. ins. Sq. ins. × 1·27324 = circ. ins.

At the present time N.H.P. is a useless commercial term, generally depending upon size of cylinder, and irrespective of pressure or speed.

Sometimes N.H.P. for non-condensing engines was $d^2 \times \sqrt[3]{\text{stroke ft.}} \div 20$, for simple condensing engines $d^2 \div 30$, and for compound engines $(D^2 + d^2) \div 33$ or 30.

Admiralty N.H.P. was formerly used in classifying the power of marine engines,

$= \text{area sq. ins.} \times \text{speed ft. per min.} \times 7 \div 33{,}000.$
$= d \text{ ins.} \times \text{speed ft. per min.} \div 6{,}000.$
$=$ about one-sixth of the indicated H.P.

Seaton's estimated H.P.

$= D^2 \text{ l.p. cylr.} \times \sqrt{p} \times \text{revns. per min.} \times \text{stroke ft.} \div 8{,}500$

Lloyds' Committee N.H.P. (1872,)

$$= \tfrac{1}{2}\left(\frac{D^2 \times \text{stroke ft.}}{630} + F\right),$$

where F = total width fire-grate ins.

N.E.C. Inst. Eng. and Shp. (1877) *Normal* I.H.P.

$=$ for screw engines $\frac{1}{100}(D^2 \times \sqrt[3]{\text{stroke ft.}} + 3\text{ B}) \sqrt[3]{p}$
$=$ for paddle engines $\frac{1}{160}(D^2 \times \sqrt[3]{\text{stroke ft.}} + 5\text{ B.}) \sqrt[3]{p}$

where B = the heating surface of the boilers in sq. ft., and if there are two low press. cylrs. D^2 = sum of sqs. of diams.

Indicated H.P. = mean p lbs. sq. in. from indicator diagram $\times$ area of piston (+ same for other pistons) $\times$ speed ft. per min. $\div$ 33,000

$$\text{or} \quad \frac{p.l.a.n}{33{,}000}$$

p being mean pressure, l length of stroke, a area of piston, n number of strokes per min.

Effective H.P. = actual H.P. of work done, or useful effect given out from engine, either estimated, or found by

friction brake, or by measurement of work performed. It is the net work done by the engine after deducting friction and loss. The Effective H.P. of any engine, compared with the steam used, is the measure of its efficiency or economy.

Brake H.P. = the power given off from the crank shaft, through the flywheel, or a pulley, to an absorption or transmission dynamometer.

French H.P. (*Force de cheval* or *Cheval-vapeur*)

= 450 kilogrammètres per min.
= 32,549 ft. lbs. per min.

For *Boiler* H.P., see § 316.

378. Steam worked Expansively.

When cut off at any part of stroke, as $\frac{1}{n}$; then its

Efficiency $= 1 + \text{hyp. log } n$.

Mean pressure $= m = \frac{1}{n} p\,(1 + \text{hyp. log } n)$.

Initial pressure $= \dfrac{m\,n}{1 + \text{hyp. log } n}$.

Pressure at any point in the expansion curve at x distance from commencement of stroke $= \dfrac{\frac{1}{n}s}{x}\,p$.

Advantage of working expansively $= \dfrac{U\,n}{p\,s}$ to 1, or $100\left(\dfrac{U\,n}{p\,s} - 1\right)$ per cent gain.

Distance travelled to attain maximum velocity

$$= \frac{p\,s}{m\,n} \text{ or } \frac{s}{1 + \text{hyp. log } n}.$$

Cut-off for maximum efficiency (*Pole*)

$$= \frac{\dfrac{24{,}250}{p} + 65}{\dfrac{24{,}250}{\text{useless resistances}} + 65}$$

Terminal pressure $= \dfrac{p}{n}$, or $\dfrac{1}{n}$ th of p.

Units of work per sq. in. of piston in one stroke

$$= p\,\frac{s}{n}\,(1 + \text{hyp. log } n).$$

All pressures are measured from perfect vacuum, the atmospheric line is a variable element.

Above formulæ assume theoretically perfect indicator diagrams and expansion according to Boyle and Marriotte's law.

In ordinary land engines the mean pressure found above must be multiplied by ·8 to give the mean pressure from an indicator diagram.

$$\text{Com. log.} \times 2{\cdot}3026 = \text{hyp. log.}$$

379. Crank and Piston Notes.

a = Length of connecting rod.
b = Length of crank.
x = Distance of piston from end of stroke furthest from crank, when point of maximum leverage is reached.
x' = Distance of piston as before, when crank has made quarter revolution from dead centre.

$$x = (a + b) - \sqrt{a^2 + b^2} \qquad x' = (a + b) - \sqrt{a^2 - b^2}.$$

These values divided respectively by $2\,b$ will give the proportion of stroke where these points occur.

All the distances are measured from the end of stroke furthest from crank.

p = pressure on piston (total).
p_1 = thrust in connecting rod.
θ = angle of do. with horizontal.
p_2 = pressure on guide bar.
p_3 = turning effort on crank.
ϕ = angle of crank with horizontal, then

$$\sin\phi = \sin\theta\,\frac{a}{b}$$

$$\sin\theta = \sin\phi\,\frac{b}{a}$$

$$p_1 = p \times \operatorname{cosec}\theta$$
$$p_2 = p \times \tan\theta$$

Between tangential points in 1st and 4th quadrants.

$$p_3 = p \times \operatorname{cosec}\theta \times \sin(\phi + \theta).$$

Beyond do. do. through 2nd and 3rd quadrants.

$$p_3 = p \times \operatorname{cosec}\theta \times \sin(\phi - \theta).$$

380. Slide Valve Notes.

r = ratio of cut-off in cylr.
T = travel of slide.
L = lap " "
l = lead " "
w = width steam port.

$$T = 2\,(w + L)$$
$$l = (\tfrac{1}{2}\,T\sqrt{1 - r}) - \tfrac{1}{2}\,l$$
$$r = 1 - \left(\frac{2\,L + l}{T}\right)2.$$

Effect of obliquity of connecting rod is to make cut-off

later on the out-door stroke and earlier on the in-door stroke, or in other words to draw all points of an indicator diagram nearer the crank or stuffing box end of a cylinder.

381. Point of Cut-off

when slide is set with equal lead.

A = dist. travelled by piston before cut-off.
B = remainder of stroke.
C = dist. centre crosshead to centre crank shaft at point of cut-off = $a + b - A$.

Cut-off on out-door stroke = A

Do. in-door „ $= A - \dfrac{A \times B}{C}$

To equalise cut-off, shift slide.

382. Number of Expansions.

The steam is usually expanded in

Simple condensing engines	from	3	to	5	times.
Two cylinder compounds	„	7	„	9	„
Triple compounds	„	12	„	15	„
Quadruple compounds	„	16	„	18	„

383. Ordinates to Hyperbolic Expansion Curves.

Initial pressure = p.

Cut-off at $\frac{2}{10}$, then ordinate at $\frac{3}{10} = \frac{2}{3}\,p$.
„ „ „ $\frac{4}{10} = \frac{2}{4}\,p$.
„ „ „ $\frac{5}{10} = \frac{2}{5}\,p$, and so on.

Cut-off at $\frac{1}{4}$ $(= \frac{5}{20})$, then ordinate at $\frac{3}{10}$ $(= \frac{6}{20}) = \frac{5}{6}\,p$.
„ „ „ $\frac{4}{10}$ $(= \frac{8}{20}) = \frac{5}{8}\,p$.
„ „ „ $\frac{5}{10}$ $(= \frac{10}{20}) = \frac{5}{10}\,p$.
and so on.

384. Simpson's Rule.

For area of any irregular figure.

Divide area into any even number of parts by odd number of lines or ordinates. Take the sum of the extreme ordinates, four times the sum of the even ordinates, and twice the sum of the odd ordinates (omitting the first and last ordinates), multiply the total by one-third of the distance between ordinates, this equals the area.

For indicator diagram, divide length into ten equal parts by eleven lines, measure effective length of each, and number them. Then

(1st + 11th) + 4 (2nd + 4th + 6th + 8th + 10th)
+ 2 (3rd + 5th + 7th + 9th) ÷ 30 = mean pressure.

385. Resistance in Steam Engines.

1. The load or useful work.
2. The friction of the unloaded engine, = 1 to 3 lbs. per sq. in.
3. Additional friction due to the load = say $\frac{1}{7}$ of mean pressure.
4. Back pressure = 4 to 5 lbs. above vacuum for condensing engines, or 15 to 17 lbs. above vacuum for non-condensing engines.

The coefficient or modulus will then be ·6 to ·75.

386. Economy of High Pressure Steam.

The pressure of steam increases in a greater ratio than its density, whence it follows that the higher the pressure to which the steam is raised, the less *proportionate* quantity of water it contains, and therefore the less fuel is consumed, since a given quantity of fuel will evaporate the same weight of water at all temperatures.—*Pole.*

387. De Pambour's Principles.

1. When the engine has attained a uniform motion, the work done by the steam in the cylinder is equal to the work which is due to the total resistance.

2. The steam which is generated in the boiler is equal to that expended in the cylinder.

388. Area of Steam Ports.

A = area of piston.
a = area of steam port.
b = area of exhaust port.
v = velocity of piston ft. per min.

Baker (Weale's Series, 'Stm. Eng.,' p. 71) Watt's condensing engines, $a = 1$ sq. in. per N.H.P.

Bourne ('Handbk. Stm. Eng.,' p. 313), $a = 1$ sq. in. per N.H.P. or $\frac{1}{25}$ A. Also $a =$ diam. cylr.$^2 \times v \times \cdot 032 \div 140$.

Burgh ('Slide Valve,' p. 10), high press. eng., $a =$ H.P $\times \cdot 6$ or $\cdot 5$. Low press. eng., $a =$ H.P. $\times 1 \cdot$ to $\cdot 75$.

Rankine ('Stm. Eng.,' p. 414), $a = \frac{1}{25}$ A for v 200 to 240.

Sir W. G. A. & Co. $a = \frac{1}{24}$ A, $b = 2a$, $v = 200$.

Adams, $a = \frac{1}{12}$ to $\frac{1}{15}$ A, $b = 1\frac{3}{4}a$, $v = 250$ to 300.

Shapton, $a =$ diam. cylr.$^2 \times \cdot 038$.

Rigg, $a = A \times v \div 6000$.

389. Watt's Governor

Usually makes 30 revolutions per minute; then $h = 39 \cdot 1$ ins. = length of London seconds pendulum. Whole arm 3, upper portion 2, link 2, variation of velocity 10 per cent. Weight of ball = $3 \cdot 174 \times$ resistance of throttle valve connections. Generally:—

w = weight required to open throttle valve in lbs.
W = weight of one ball of governor in lbs.

L = whole length centre of suspension to centre of ball in inches.

l = length from centre of suspension to centre of attachment of link in inches.

h = height from centre line of balls when rotating at given speed to centre of suspension in inches.

R = revolutions per minute of governor.

$$h = \frac{35200}{R^2}, \qquad W = \frac{100\,l\,w}{10\,L}.$$

$$\text{Wt. of cast iron ball} = \frac{d^3}{7 \cdot 27}. \qquad \text{Diam.} = \sqrt[3]{7 \cdot 27\,W}.$$

—*Hann.*

NOTE.—In the Watt governor, the virtual point of suspension does not coincide with the actual points, owing to the pendulum arms being pivoted to projecting lugs at top of spindle. For accurate work the measurements should be taken to the virtual point of suspension, which is found by producing the centre line of pendulum rods to intersect with vertical axis.

390. FLYWHEELS, NOTES AND FORMULÆ.

Centrifugal force in lbs. radially

$$= \frac{W\,v^2}{r\,g} = \cdot 00034\,r\,W\,R^2$$

= tension in arms, divided by number of arms for tension in each.

d = mean diam. of rim in ft.

W = weight of rim in lbs.

R = revns. per min.

M = ft. lbs. momentum at 1 revn. per min.
U = units of work (ft. lbs.) accumulated in flywheel at any velocity.

$$M = \frac{W d^2}{23000} \qquad U = M R^2.$$

E = excess of demand or supply in any given time in ft. lbs.

R max. R min. = greatest variation allowed in speed, i. e. revns. per min.

$$M = \frac{E}{R^2 \text{ max.} = R^2 \text{ min.}}$$

The diameters of flywheels will be as $\sqrt[5]{M}$, the dimensions of rim being proportional to diameter.

—*Perry.*

n = number of revns. per sec.
r = effective radius of gyration in ft.
U = units of work stored in wheel.

$$U = \frac{W (2 \pi r n)^2}{2 g}.$$

Variation from mean velocity not to exceed $\frac{1}{m}$ usually $\frac{1}{20}$ to $\frac{1}{60}$.

a = area of section of rim in sq. ins.

$$a = \frac{H P \times 1803 \times m}{r^3 \times R^3}.$$

$$\text{Wt. in tons} = \frac{H P \times 2275 \times m}{r^2 \times R^3}.$$

$$\text{Mean radius} = \frac{12{\cdot}17}{R} \times \sqrt[3]{\frac{H P \times m}{a}}.$$

—*Morin.*

R = revns. per min.
A = sectional area rim sq. ft.
r = radius ft. to inside of rim.
H = I.H.P. of engine.
n = ratio of mean velocity to difference between mean and either extreme (say 10 for a diff. of 10 per cent.).

$$r = \frac{12}{R} \times \sqrt[3]{\frac{n H}{A}}.$$

—*O. Byrne.*

391. Investigation of Flywheels.

$\frac{W}{g}$ = mass (m), $\frac{v^2}{2g}$ = height (h), kinetic energy $= \frac{1}{2} m v^2$, potential energy $= W h$, accumulated work $= \frac{W v^2}{2 g}$, then

$$\frac{W v^2}{2 g} = W h = \tfrac{1}{2} m v = M R^2$$

but

$$v^2 = \left(\frac{2 \pi r R}{60}\right)^2 = R^2 \left(\frac{2 \pi r}{60}\right)^2 \therefore \frac{W}{2 g}\left(\frac{2 \pi r}{60}\right)^2 = M.$$

or

$$W r^2 \frac{4 \times 9 \cdot 87}{3600 \times 64 \cdot 4} = \frac{W r^2}{5871} = M.$$

$$\therefore \text{Energy of flywheel} = \frac{W r^2}{5871} \times R^2.$$

Energy stored up in any rotating body $= \frac{1}{2} I a^2$, where I = moment of inertia about the axis $= \Sigma m y^2$, a = any velocity in radians per sec.

$$a = \frac{2 \pi R}{60} \qquad \therefore \text{Energy} = \tfrac{1}{2} I \left(\frac{2 \pi R}{60}\right)^2 = I \frac{\pi^2 R^2}{1800}.$$

$$\therefore \text{M of flywheel} = \frac{I \pi^2}{1800} = \cdot 00548 \, I.$$

but

$$\text{M of flywheel} = \frac{W\,r^2}{5871} \qquad \therefore \cdot 00548\, I = \frac{W\,r^2}{5871}.$$

and

$$I = \frac{W\,r^2}{5871 \times \cdot 00548} = \frac{W\,r^2}{32 \cdot 17}.$$

392. Strength of Crank Pin.

p = uniformly distributed load in lbs.
l = length of journal in inches.
d = diameter of journal in inches.
f = greatest safe stress per square inch.

say, wrought iron	..	6000 to 9000.
steel	..	9000 to 13500.
cast iron ..	..	3000 to 4500.

$\frac{p\,l}{2}$ = greatest bending moment at fixed end of journal.

$$M = \frac{\pi}{32} d^3 = \cdot 0982\, d^3 = \text{modulus of circular sec.} = \frac{2\,I}{d}.$$

$$I = M\,\frac{d}{2} = \frac{\pi}{32} d^3 \times \frac{d}{2} = \frac{\pi}{64}\, d^4 = \cdot 0491\, d^4 = \text{moment of inertia of circular section.}$$

$$p = \cdot 0982\, d^3 f \frac{2}{l} = \frac{\cdot 1964\, d^3 f}{l} = \frac{d^3 f}{5 \cdot 1\, l}.$$

$$d = \sqrt[3]{\frac{p\,l}{\cdot 1964 f}} = \sqrt[3]{\frac{5 \cdot 1\, p\, l}{f}}.$$

393. Notes on Calculation of Engine Shafts.

By law of virtual velocities, mean pressure on crank pin

$$= d^2 \frac{\pi}{4} \times m \times \frac{2\,s}{\pi\,s} = \frac{d^2\,m}{2} = \frac{a\,m}{1 \cdot 57};$$

but the force being irregular, the maximum must be taken for the crank and flywheel shaft; say full pressure on piston acting at radius of crank,

$$= \frac{d^2 \pi p}{4} \text{ at radius } \frac{s}{2}$$

Beyond the flywheel $\frac{d^2 m}{2}$ may be substituted for $\frac{d^2 \pi p}{4}$, as the strain will there be practically uniform.

394. Calculation of Engine Shafts.

p = maximum boiler pressure, lbs. per square inch.
m = mean pressure in cylinder „ „ „
s = stroke of piston in feet.
d = diameter „ „ inches.
a = area „ „ square inches.
f = factor of safety.

	Steam engine.	Hydc. eng. and steam winches.
Wrought iron and steel ..	$\frac{1}{6}$	$\frac{1}{10}$
Cast iron	$\frac{1}{10}$	$\frac{1}{15}$

k = ultimate strength, 1-inch bar, 1 foot radius.

	Cast steel.	Mild steel.	Wrot. iron.	Cast iron.
	1250	1000	750	600
c = constant or safe load = fk.				
Steam engine ..	200	175	125	60
Hydraulic engine, &c.	125	100	75	40

D = diameter of shaft in inches.

For crank shaft:

$$D = \sqrt[3]{\frac{d^2 \times \pi \times p \times s}{4 \times 2 \times f \times k}} = \sqrt[3]{\frac{d^2 p s}{2 \cdot 5 c}}.$$

And beyond the flywheel:

$$D = \sqrt[3]{\frac{d^2 \times m \times s}{2 \times 2 \times f \times k}} = \sqrt[3]{\frac{d^2 m s}{4 c}}.$$

For two cylinders, let diameter = D + ·15 D.
For three cylinders „ „ = D + ·3 D.

395. Coefficient of Steam Engines.

Horizontal high pressure direct acting pumping engine working against accumulator pressure of 700 lbs. per sq. in., specified as 84 H.P. at 60 revolutions per min. 2 steam cylinders each 16″ diam. × 20″ stroke; 2 double acting force pumps with piston, each 5·1 ins. diam. = $\frac{1}{10}$ area of steam piston, and ram 3·6 ins. diam. = $\frac{1}{2}$ area of pump. Boiler pressure 60 lbs. per sq. in. by gauge. Cut-off $\frac{2}{3}$ stroke. Mean pressure by calculation = 56 lbs. per sq. in., by indicator diagram 45 lbs. per sq. in.

16 ins. diam. = 201·06 sq. ins. area, 5·1 ins. diam. = 20·43 sq. ins. area, 3·6 ins. diam. = 10·18 sq. ins. area.

$$\text{Power} = \frac{201{\cdot}06 \times 45 \times 2 \times 120 \times 1\frac{2}{3}}{33000} = 109{\cdot}67 \text{ I.H.P.}$$

$$\text{Effect} = \frac{20{\cdot}43 \times 700 \times 2 \times 60 \times 1\frac{2}{3}}{33000} - 5\% \text{ loss} = 82{\cdot}33 \text{ E.H.P.}$$

$$\text{Coefficient} = \frac{82{\cdot}33}{109{\cdot}67} = {\cdot}75,$$

or 75 per cent. on the indicated horse-power.

In connection with the above engine the following particulars may be useful. Flywheel 9 ft. diam., 2 wrot. iron Lancashire boilers, 6 ft. diam. × 20 ft. long., 2 flues, each 28 ins. diam., with 5 Galloway tubes. Double acting lift pump. Tank, 1500 gals., for return water. 18 inch accumulator, 23 ft. stroke.

396. Comparison of Steam Engines.

Engines same type. Boiler pressure same. Cut-off same. Multiplier for proportionate linear dimensions equals

$$\sqrt{\frac{\text{required H.P.}}{\text{original H.P.}}} = \sqrt{r}.$$

and the revolutions per min. will be

$$\frac{\text{original revolutions}}{\sqrt{r}}$$

without allowing for difference in proportion of friction. Friction varies approximately as $\sqrt[3]{r}$.

397. Link Motions.

Stephenson's.—Link curved, concave side towards eccentrics, shifted to vary position of motion block, block moving in direct line with slide rod, lead increasing towards mid-gear with open rods and decreasing with crossed rods.

Gooch's.—Link curved, concave side towards spindle, maintained in central position by rod swinging on a stud, motion block shifted in link by radius rod connected to valve spindle, lead constant.

Allan's.—Link straight, link and motion block moved in opposite directions by rocking shaft, lead increasing towards mid-gear with open rods, and decreasing with crossed rods.

Joy's.—Link curved, moving on a fixed pivot, concave side towards valve, no eccentrics; pendulum rod attached to centre of connecting rod at one end and to radius bar at other end; another bar pivoted on motion block, one end connected to valve rod and other end to pendulum rod; link moved on centre to alter valve; distribution of steam symmetrical.

398. Tractive Force of Locomotives.

a = area of piston in sq. ins.
l = length of stroke in ft.
n = number of cylinders.
D = diam. driving wheel in ft.

Then the tractive force at circumference of driving wheels for each lb. per sq. in. mean effective pressure on piston.

$$= \frac{2\,a\,n\,l}{\pi\,D}\,.$$

Also let μ = adhesion of wheels to rails (say ·2)
W = weight on driving wheels,
then $W\mu$ = actual total tractive force.

The mean effective pressure on piston is commonly assumed to be 85 per cent of boiler pressure, but this will be different for each design of valve gear, other things being equal.

399. Adhesion of Loco. Wheels.

Locomotive driving wheels will commence to slip if the force at circumference equals about

$\frac{1}{5}$ of the load	= 448	lbs. per ton.
Westinghouse and Galton	= 246·4	,,
Poirèe	= 465·9	,,
Pennsylvania Railroad ..	= 550	,,
Northern Pacific Railroad	= 670	,,

—'*Eng. Mech.*'

400. Resistance on Railways.

Straight and level railway, in good condition, resistance (R) in lbs. per ton of total load (W).

$$= \frac{v.\ \text{miles per hour}^2}{171} + 8.$$

$$\text{Do. on incline of 1 in } m = \text{R} + \left(\frac{1}{m}\,\text{W} \times 2240\right)$$

On Prussian railways, R is taken at $\frac{1}{100}$ W = 22·4 lbs. per ton.

By experiment in railway goods stations, R = 30 lbs. per ton moving slowly.

401. Definitions relating to Screw Propellers.

Length = $A^1\ B^1$ measured along the axis of the shaft.

Angle = P O H, which is a plane triangle when developed.

Pitch = The distance traversed on $A^1\ B^1$ for one complete revolution of A^1 P.

Slip = The difference between the theoretical forward motion, calculated from the pitch of the screw, and the actual progress of the ship.

Area = A^1 P O B, surface of blade in square feet.

Thread or *Helix* = Outer edge of blade, O P.

Diameter = Diameter of cylinder circumscribing the thread of screw. A^1 P = radius.

402. Speed in Knots.

Speed in knots × 1·15 = miles per hour.

6080 feet = 1 knot.

5280 ,, = 1 mile.

$$\text{Ft. per min.} \div 88 = \text{miles per hour.}$$
$$\text{Do.} \quad \div 101\tfrac{1}{3} = \text{knots} \;,, \quad ,,$$

Speed of ship in knots (per hour)

$$= \sqrt[3]{\frac{\text{I.H.P.} \times \text{sectional coeff. of performance, say } 600}{\text{area immersed midship section, sq. ft.}}},$$

or

$$= \sqrt[3]{\frac{\text{I.H.P.} \times \text{displacement coeff. of performance, say } 240}{\text{cube root of sq. of displacement in tons}}}.$$

403. Notes on Screw Propellers.

In the common form of propeller the screw surface is generated by a line perpendicular to the axis of the shaft revolving round the shaft and progressing uniformly along it.

Screw surfaces are also generated by a line at right angles to a conical surface; in some cases the vertex of the cone points aft, and in others forward. In some the surface is traced out by a line perpendicular to a sphere. The object in such cases being to diminish, if possible, centrifugal action of the water.

Screws of same pitch have different angles if their diameters differ. Angle reducing as diameter increases.

The screws are either right- or left-handed, and may have two, three, or four blades.

404. Slip of Screw Propeller.

Slip is less when pitch is small and speed great, but more danger from heated bearings. When pitch is small, the propeller is less liable to break from a blow.

The slip is diminished, cæteris paribus, by

1. Decreasing the angle of the screw.
2. Increasing the diameter of the screw.
3. Increasing the length of the screw.

But the friction increases rapidly with the surface of the blade.

The indicated horse power varies as the square of the speed of the ship × number of revolutions of screw × pitch.

The most economical speed is when the vessel steams half as fast again as the opposing current, or half as fast again as a vessel it desires to overtake.

405. Negative Slip.

Negative slip in screw propellers is caused either by the skin friction of the ship giving a forward velocity to the water in which the screw works, depending upon the lines of the ship, and the position and size of screw; or it is caused by an increase of pitch due to the straining of a weak propeller by the pressure of the water; or it is due to the pitch of the propeller being incorrectly estimated.

406. Pitch of Screw Propeller.

Ordinary propellers have the pitch uniform throughout each blade, the angle varying with the distance from the axis, originally known as Smith's propeller.

Screws of increasing pitch are sometimes used, and known as Woodcroft's propeller.

Propellers with two blades are common in large ships, but those with three or four blades are better when the draft is small or in a rough sea.

Feathering-screws have the blades pivoted so that the angle, and thereby the pitch, may be altered.

The pitch of a screw varies with the ratio of the circle described by the screw to the immersed midship section.

407. Alteration of Pitch.

With same mean pressure on piston, for small alterations of pitch

$$\text{pitch} \times \text{knots}^2 = \text{constant.}$$

and

$$\text{pitch}^3 \times \text{revolutions}^2 = \text{constant.}$$

∴ increasing pitch reduces revolutions and speed.

—*Somerscales.*

408. Indicated H.P. required for Screw Propeller.

R = revns. per min.
D = diam. of propeller in ft.
L = length „ „
P = pitch „ „
s = slip „ in fraction of unity (as $\frac{1}{4}$).
θ = angle of blade at periphery.

$$\text{I.H.P.} = \frac{D^3\,R^3}{480{,}000}\left(L\,s\cos\theta + \frac{1}{9}\right).$$

$$\text{Knots (per hour)} = \frac{3\,P\,R}{304}\,(1 - s).$$

409. Built-up Crank Shafts.

City of Rome s.s., Whitworth compressed steel, Difference in diameter of fitting parts allowed for shrinkage $= \frac{1}{1000}$ diam.

410. Paddle Wheels.

k = speed of vessel in knots.
N = revns. of engine per minute.
r = rad. of rolling circle in ft., or circle with circumferential velocity equal to ship's motion.

$$\frac{6080\,k}{60} = 2\,\pi\,r\,\text{N}.$$

$$\therefore\; r = \frac{6080\,k}{60\,\pi\,2\,\text{N}} = \frac{16\,k}{\text{N}}.$$

R = rad. outside wheel in ft.
b = breadth radially of float-board or paddle in ft.
m = mean radius, to centre of gyration, of float-boards.

$$m = r - b + \sqrt[3]{\frac{(\text{R} - r + b)^4}{4\,b}}.$$

v = circumferential velocity ot centre of pressure of float-boards in ft. per sec.

$$v = \frac{2\,m\,\pi\,\text{N}}{60} = \cdot 10472\,m\,\text{N}.$$

a = area of float-boards in sq. ft.
p = pressure in lbs. on vertical float-board.

$$p = \frac{62\cdot 5\,a}{2\,g} \times \left(v - \frac{6080\,k}{3600}\right)^2 = a\,(v - 1\cdot 7\,k)^2.$$

n = number of paddle wheels.

$$\text{Eff. H.P. required} = \frac{v\,n\,p}{33000}.$$

—*Hann and Gener.*

411. Efficiency of Paddle Wheels.

Common, light draft	= ·666
„ deep draft	= ·553
Feathering (Morgan's patent) all depths	= ·666

412. Equilibrium of Floating-bodies, as Ships.

When a floating body is in equilibrium, the centre of gravity of the body and the c. g. of the displaced fluid are in the same vertical line. When the floating body is moved through a small angle, the intersection of the originally vertical line through c. g. of body, with vertical line through c. g. of now displaced fluid, is called the *metacentre* (Bouguer). The floating body will return to its original position so long as the metacentre remains above the c. g. of body. The equilibrium is stable, unstable, or indifferent, respectively, as the metacentre falls above, below, or coincides with the c. g. of the body.

SECTION XII.

HYDRAULIC MACHINERY.*

413. Summary of Hydraulics.

The quantities discharged from different apertures of similar character vary directly as the areas, and as $\sqrt{\text{altitudes}}$.

On account of friction, a small orifice discharges propor-

* See lecture by the author on "Hydraulic Machinery, Past and Present," read before the Railway Officials' Association in 1880. Demy 8vo, 42 pp., and folding plate of illustrations (Spon, 1*s*.).

tionally less water; and of several orifices having the same area, that with the smallest perimeter discharges most: hence a circular orifice is most advantageous.

Water issuing from a circular aperture is contracted at distance of $\frac{1}{2}$ diameter from orifice, from 1 to $\begin{cases} \text{Bossut} & \cdot 666 \\ \text{Venturi} & \cdot 631 \\ \text{Eytelwein} & \cdot 64 \end{cases}$ in area, called "vena contracta." Vein contracts more with greater head, therefore discharge slightly diminished below theoretical discharge due to altitude.

The discharge through a tube of diameter = length is the same as through simple orifice of equal diameter. The discharge increases up to a length of 4 diameters.

The discharges through horizontal conduit pipes are directly as the altitudes and inversely as $\sqrt{\text{length}}$. To have perceptible and continuous discharge, head must not be less than $\frac{\text{length}}{1300}$. Vertical bends discharge less water than horizontal, and horizontal bends less than straight pipes.

In prismatic vessels twice as much is discharged from the same orifice if the vessel be kept full, during the time it would take to empty itself.

414. Pressure of Water.

Water transmits pressure equally in all directions. (Pascal), and its own weight acts as additional pressure in proportion to the depth from surface. Pressure is perpendicular to containing surface. Water is only compressible to a very small extent. Pressure per unit of area is affected solely by depth, and is entirely independent of extent of surface.

Area of any portion of containing surface in sq. ft. × distance of its centre of gravity in ft. from surface of liquid

× weight of liquid per cub. ft. = pressure upon that portion of containing surface.

The "centre of pressure" on a plane surface, or point where pressures would be balanced by a resistance, is $\frac{1}{3}$ height, or $\frac{2}{3}$ down from surface.

The pressure of the air is not able to sustain a column of water more than 34 feet high, hence water cannot by any possibility be raised by direct suction from a greater depth —the exact amount varies with the barometric pressure.

415. Flotation Power of Water.

When a solid body floats on a liquid the weight of the liquid displaced is equal to the weight of the body.

When a heavy body is immersed in water it loses weight equal to the weight of water displaced.

$$\text{Specific gravity} = \frac{\text{Weight of body in air}}{\text{Weight of equal bulk of water}},$$

or

$$= \frac{\text{Weight of body in air}}{\text{Weight in air} - \text{Weight in water}}.$$

Solid cast iron loses $14\frac{1}{4}$ per cent. of its weight when immersed in water.

416. Torricelli's Theorem.

Particles of fluid escaping from an orifice possess the same velocity as if they had fallen freely *in vacuo* from a height equal to that of the fluid surface above the centre of the orifice.

417. Comparison of Discharge through various Apertures.

Theoretical velocity in feet per second =

$$\sqrt{\text{Head in ft.} \times 2\,g}.$$

Theoretical discharge being 1·
Short tube projecting into reservoir = ·5.
Orifice in thin plate, 1″ diameter = ·62.
Tube 2 diameters long = ·82.
Conical tube approaching form of contracted vein = ·92.
„ „ edges rounded off = ·98.

Or, say theoretical velocity ft. per sec. = 8·04 $\sqrt{\text{head ft.}}$

Effective velocity through orifices of the form of vena contracta, well placed sluices, large bridge openings, &c. .. .. .. $= 7 \cdot 5 \sqrt{h}$.
„ large vertical pipes and narrow bridge openings .. .. .. $= 6 \cdot 75 \sqrt{h}$.
„ sluices without side walls, dock gates, and mill stream sluices. $= 5 \sqrt{h}$.

418. Practical Discharge of Water.

h = head in feet.
c = discharge in cub. ft. per min.
a = area in square feet.

$$k = \text{constant} = \begin{cases} 450 \text{ for bridges, \&c.} \\ 400 \text{ „ pipes „} \\ 300 \text{ „ ordinary sluices.} \end{cases}$$

$$c = k\,a\sqrt{h}, \quad h = \left(\frac{c}{k\,a}\right)^2, \quad a = \frac{c}{k\sqrt{h}}.$$

—*Beardmore.*

When the outlet is "drowned" the head will be the difference in level between water over inlet and outlet.

419. Weight and Bulk of Water.

A standard or imperial gallon of water was formerly 277·274 cubic inches, is now 10 lbs. avoirdupois at 62° Fahr. and 30" bar. = 277·123 cubic inches, or ·160372 cubic feet. —*Capt. E. M. Shaw.*

A cubic foot of pure water at its point of maximum density, 39° F., weighs 998·8 ounces = 62·425 lbs. —*Twisden.*

Standard weight of water = 62·321 lbs. per cub. ft. —*Sale of Gas Act*, 1859.

The experiments of the Standards Office of the Board of Trade show that a cubic inch of water weighs 252·286 grains instead of 252·458 grains, of which 5760 go to the pound Troy, and 7000 to the pound Avoirdupois, therefore a gallon of water now equals 277·463 cubic inches. —'*The Engineer*,' 1889.

U.S. standard gallon weighs $8\frac{1}{3}$ lbs. and contains 231 cub. ins.

420. Useful Numbers in connection with Water.

Cubic feet $\times$ $6\frac{1}{4}$ = gallons.
Cubic feet per minute $\times$ 9000 = gallons per 24 hours.
Head in feet $\times$ ·434 = lbs. per square inch.
Lbs. per square inch $\times$ 2·3 = feet-head.
Tons $\times$ 224 = gallons.
Diameter inches^2 $\div$ 10 = gallons per yard.
Weight of sea water = 1·027 wt. of fresh water.

421. Velocities of Streams.

s = surface velocity ins. per sec. centre of stream.
b = bottom „ „ „ „

m = mean velocity ins. per sec. of whole stream.

$$b = (\sqrt{s} - 1)^2,\ m = \cdot 8 \frac{s + b}{2},\ \text{or } m = \cdot 8\,(s - \sqrt{s} + \cdot 5).$$

—*Du Buat.*

$$m = \cdot 705\, s + \cdot 01\, s^2.$$

—*von Wagner.*

422. Discharge over Weirs.

h = true head from sill to still surface in feet.
c = discharge in cub. ft. per min. per ft. width.

$$c = 214 \sqrt{h^3}$$

When the water passes the point where the constant head begins to deflect, with an appreciable initial velocity $= v$. ft. per sec.

$$c = 214 \sqrt{h^3 + \cdot 035\, v^2 h^2}$$

For small weirs:
l = length of weir or notch in inches.
g = gallons discharged per minute.
d = depth of head in inches.

$$g = 2\, l \sqrt{d^3}.$$

423. Discharge over Weirs per Foot Width.

h = height of flow on edge of rule over square notch or edge of horizontal weir.
c = cub. ft. per min.

h = 1	inch,	then c =	5·10
$1\frac{1}{4}$	,,	,,	7·14
$1\frac{1}{2}$	,,	,,	9·23
$1\frac{3}{4}$	,,	,,	11·78
2	,,	,,	14·43

—*Hawksley.*

424. Rivers, Sewers, Drains, &c.

D = hydraulic mean depth in feet.

of streams or pipes partly full $= \dfrac{\text{sectional area}}{\text{wetted perimeter}}$

of pipes running full or half full only $= \dfrac{\text{diameter}}{4}$.

f = fall in feet per mile.
M = mean velocity in feet per min.
d = diam. of pipe in feet.
l = length in feet.
h = head or fall in feet.

I = mean hydraulic inclination $= \dfrac{l}{h}$.

$$M = \sqrt{D \times 2f} \times 55, \quad c = aM. \qquad \text{—\textit{Beardmore.}}$$

$$M = \frac{6000\sqrt{D}}{\sqrt{I}}. \qquad \text{—\textit{Leslie.}}$$

$$c = \frac{2356\sqrt{d^5}}{\sqrt{I}}. \qquad \text{—\textit{Eytelwein.}}$$

$$M = 92{\cdot}26\sqrt{I\,D}.$$

425. Natural Evaporation of Water.

Mean evaporation of water from open surface in London, large body of water 21 inches per annum, small body 50 inches; rainfall during same period 25 inches.

426. Waterwheels.

Undershot Wheel.—Float boards radial, or inclined 20° towards current when not used in tidal stream. Breadth

may equal or exceed diameter. Maximum efficiency when velocity of wheel equals half velocity of stream.

Breast Wheel.—Floats shrouded or covered at the sides and curved to form buckets. Breastwork of masonry built up round wheel as high as centre line. Stream led down a masonry slope to act on wheel by momentum and gravity. Suited for moderate supply of water and fall of 6 or 8 feet.

Overshot Wheel.—Floats formed into buckets. Water led in trough to top of wheel. Ratio of width to diameter usually small. Requires less water to drive it than the other forms, and is more than twice the power of an undershot wheel of same size. Fall must not be less than diameter of wheel. Smeaton found that in ordinary wheels the velocity of circumference should not exceed 3 feet per second.

Poncelet Waterwheel.—Undershot, floats curved to meet stream, maximum effect when velocity of stream equals $2\frac{1}{2}$ times velocity of wheel. Modulus = ·7.

427. Turbines.

Fourneyron's (1827).—Water admitted in centre of wheel, passing along curved guides, and discharged at circumference against guides curved in opposite direction.

Thompson's Vortex Wheel.—Water admitted at circumference and discharged at centre, can be fixed above tailrace up to 30 feet, power being obtained by suction.

Fontaine's and Jonval's Parallel Flow Wheels.—Water admitted above through fixed inclined vanes and discharged below, axis vertical, inclined vanes on wheel with angle reversed.

428. Discharge through Pipes from Natural Head.

H = head of water in ft.
L = length of pipe in ft.
d = diam. of pipe in inches
c = constant (see table)
W = cub. ft. discharged per min.

$$W = \frac{c}{\sqrt{\frac{L}{H}}}.$$

d.	*c.*	*d.*	*c.*
1	4·71	7	612·32
$1\frac{1}{4}$	8·48	8	854·99
$1\frac{1}{2}$	13·02	9	1147·61
2	26·69	10	1493·47
$2\frac{1}{2}$	46·67	12	2356·00
3	73·50	15	4115·93
4	151·02	18	6493·14
5	263·87	24	13328·0
6	416·54	30	23282·0

—*Beardmore.*

$$W = 4{\cdot}71\sqrt{\frac{d^5 H}{L}},\quad d = {\cdot}538\sqrt[5]{\frac{L\,W^2}{H}}.$$

—*Eytelwein.*

G = gallons delivered per hour.

$$d = \tfrac{1}{15}\sqrt[5]{\frac{G^2\frac{L}{3}}{H}},\qquad G = \sqrt{\frac{(15\,D)^5\,H}{\frac{L}{3}}}.$$

—*Hawksley.*

r = hydraulic mean depth in feet.

s = sine of inclination $= \dfrac{\text{total fall}}{\text{total length}}$.

v = velocity ft. per sec.

$$v = 140\sqrt{r\,s} - 11\sqrt[3]{r\,s},\qquad W = 47{\cdot}124\,d^2\,v.$$

—*Neville.*

429. Friction of Water in Pipes.

h = head in feet, d = diam. in ins.
l = length in feet, v = velocity feet per sec.

$$\text{Effective head} = \frac{4}{5}\,\frac{h}{\frac{l}{50} + d},$$

or allow $\frac{1}{3}$ to $\frac{1}{4}$ more diam. than is theoretically required for the quantity.—*Bird and Brooke.*

10 to 12 feet head is absorbed in friction per mile of pipe.—*Bateman.*

430. Delivery of Water in Pipes.

v = velocity in feet per second through pipe.
a = area of pipe in square inches.
d = diameter of pipes in inches.
W = discharge in cubic feet per minute.

$$W = \frac{v\,a}{2 \cdot 4}, \qquad v = \frac{2 \cdot 4\,W}{a}, \qquad a = \frac{2 \cdot 4\,W}{v}.$$

Approximately:

$$W = \frac{v\,d^2}{3}, \qquad v = \frac{3\,W}{d^2}, \qquad d = \sqrt{\frac{3\,W}{v}}.$$

431 Velocity of Water through Pipes and Valves.

With an Accumulator pressure of 700 lbs. per square inch, the natural velocity (theoretical) is 322·32 feet per second. It is found in practice that not more than $\frac{1}{10}$th of this can be obtained through the pipes and $\frac{1}{3}$rd through the valves, in order to maintain the proper speed for the machinery. The loss from friction in the pipes is about 1 lb. per square inch per 100 feet length, after they have been laid some time; 1 lb. additional for each bend, and 10 lbs. each branch.

In order to allow for the furring-up of the small pipes, it is not safe to reckon upon more than three times the diameter of pipe in inches as the velocity obtainable in feet per second. It is also usual to calculate the velocity through the valves at not more than 98 feet per second.

432. Mechanical Value of Fluids under Pressure.

U = units of useful work in foot-lbs.

p = pressure in lbs. per square inch.

Q = quantity used in cubic feet.

M = modulus of machine, or coefficient of effect found by experiment, and varying with class of machine or arrangement.

$$U = 144\,p\,Q\,M.$$

433. Mechanical Value of Water under Accumulator Pressure.

Theoretically the mechanical value of water under Accr. pressure of 700 lbs. per square inch (549·78, say 550 lbs. per circular inch) is 100,800 foot-lbs., or 45 foot-tons per cubic foot of water, irrespective of the time in which it is consumed; or 3·0545 H.P. per cubic foot per minute; or 1 H.P. requires ·32738 cubic feet per minute.

Approximately this equals 1 H.P. from 2 gallons of water; but practically, allowing for all losses, about 3½ gallons are required; or 4 cubic feet (= 25 gallons) will give out 100 foot-tons in work.

10 gallons will lift 1 ton to a height of 40 feet at a cost of one penny.

434. Power required to work Hydraulic Machinery.

In hotels, wharves, &c., with several machines, allowance must be made for $\frac{2}{3}$ of the machinery working to half the full height every 1½ minute.

∴ power per minute = $\frac{2}{9}$ total capacity of machinery.

At wharf with several cranes, $\frac{2}{3}$ machinery full lift, every 1½ minute.

∴ power per minute = $\frac{4}{9}$ capacity of machinery.

At railway goods stations, docks, &c., where many machines are idle at one time, say $\frac{1}{8}$ machinery full height, every $1\frac{1}{2}$ minute.

$\therefore$ power $= \frac{1}{12}$ capacity of machinery.

At small wharves where cranes are rapidly worked, all machinery, full height every $1\frac{1}{2}$ minute.

$\therefore$ power $= \frac{2}{3}$ capacity of machinery.

435. Hydraulic Pressure Accumulator,

Invented by Lord Armstrong in 1850, consists of vertical cylinder and ram, to the crosshead of which a load of 20 to 120 tons is hung to create the pressure necessary for working the machinery, obviating the use of a high tower giving a natural head of water.

The load is usually contained in a cylindrical casing Clean washed heavy Thames ballast weighing 27 cwt. per cubic yard is the cheapest and best procurable in London. Where convenient, railway ballast may be used. Iron slag is sometimes used: it has the advantage of weight, and therefore occupies less space but is expensive and very awkward to handle. Copper ore slag is not suitable, owing to the galvanic action set up. Water has been used for ballast where the pressure is required to be varied occasionally. Clay has also been used in its natural state, but is better when burnt. Iron kentledge, brickwork, cast-iron blocks and direct steam pressure have also been used by various manufacturers for producing the load.

The Accumulator is a limited reservoir of power enabling the steam engine to work at the average speed requisite to supply machinery working intermittently. The capacity is equal to the possible excess of water required by the machinery over that supplied by the engine, in a given time.

436. Pressure in Pipe-Mains.

Working pressure averages 700 lbs. per square inch when given by Accumulator, but may be from 350 to 1000 lbs.

700 lbs. per square inch = 549·78 lbs. per circular inch, equivalent to 1613·2 feet head.

All pipes subject to the Accumulator pressure to be tested to 2500 lbs. per square inch before leaving the works, and to 2000 lbs. per square inch after being laid.

Water companies' pipes to be tested with a pressure equal to 500 feet head, and while under pressure to be sounded from end to end with a 5-lb. hammer.

Pressure in water companies' mains is at maximum between 2 and 3 A.M., minimum 6 A.M. to 6 P.M., variation say from 10 to 60 lbs. per square inch.

437. Variation of Accumulator Pressure due to working of Machinery.

Normal pressure, say 700 lbs. per square inch. Average variation from 50 lbs. below to 100 lbs. above the normal pressure. Maximum variation 250 lbs. above and below, but this only occurs on a long line of pipe where the Accumulator is at some distance from the machine.

438. Friction of Accumulators.

P = pressure in lbs. per square inch taken at half stroke, Accumulator rising slowly.

p = pressure in lbs. per square inch, Accumulator falling slowly.

f = friction of ram in lbs. per square inch.

$$f = \frac{P - p}{2}.$$

At the Marseilles Docks the friction of a 17-inch Accumulator amounted to 7·355 lbs. per square inch, or not quite 1 per cent. of the gross load.—*Hawthorn.*

At Scottish Wharf the friction of a 17-inch Accumulator was 10 lbs. per square inch.

Generally,

$$f = \frac{170}{d}.$$

439. Air Accumulators.

W = working capacity in cubic feet of water.
C = mean capacity for air in cubic feet.
a = cubic feet air required at atmospheric pressure to charge Accumulator.
p = mean pressure in lbs. per square inch.
P = maximum „ „ „
P′ = minimum „ „ „

$$P = \frac{p}{1 - \frac{W}{2C}}. \qquad P' = \frac{p}{1 + \frac{W}{2C}}.$$

$$C = \frac{P' W}{2(p - P')}. \qquad a = C\frac{p}{15}$$

May be proportioned as follows:—

D = inside diameter in feet.
L = inside length in feet.

$$D = \sqrt{\cdot 4244\,W}. \qquad L = 11\,D. \qquad C = 3W.$$

Total capacity divided thus:—

Air under maximum pressure .. .. $= \frac{15}{22}$
Water „ „ .. .. $= \frac{6}{22}$
Margin from level of outlet to lowest water level .. .. $= \frac{1}{22}$

If p = 700, then P = 840 and P′ = 600.

440. Speed of Pumping

Depends entirely upon circumstances and provision made to resist shocks. Ordinary direct-acting pumping engines will run against Accumulator pressure at a piston speed of 200 ft. per minute without knocking. Large pumping engines lifting from wells run slower, and small pumps quicker.

441. Efficiency of Pumps and Accumulator.

R = any number of revolutions of engine.
r = rise of accumulator in inches for same number of revolutions.
D = diameter of accumulator ram in inches.
d = diameter of pump in inches (piston if double-acting, ram if single-acting).
s = stroke of pump in inches.
n = number of pumps.

$$\text{Efficiency} = \frac{D^2 r}{d^2 s n R}$$

$$\left.\begin{array}{r}\text{Loss per cent of working} \\ \text{capacity of pumps} \quad ..\end{array}\right\} = \frac{100 \{ (d^2 s n R) - (D^2 - r) \} .}{d^2 s n R}$$

When all parts are in good order, the loss in the pumps averages 5 per cent.

442. Packing for Force Pumps.

Cup-leathers (invented by Bramah) may be single, double, or treble. If single, the open end should be turned towards the delivery end of the pump. If double, they may be back to back, or both turned towards delivery end of pump.

If treble, two should be back to back, and the third put as a duplicate to the one turned towards delivery end. In all cases the back of the leather should be closely supported by a washer curved to the shape of the leather. Double leathers back to back are generally used, and last from 2 days to 4 months, average say 1 month. Only the middle of the back of best oil-dressed hide is used.

Spun-yarn is sometimes used, the same as for glands of hydraulic machinery generally. It is plaited and formed into rings by splicing, soaked in tallow, and screwed up in a mould to form solid rings of exact size to fit pump.

Rope is sometimes used in the same way, being selected of the exact diameter required. The two latter methods are said to last from 4 to 6 months, but there is probably more leakage than with leathers.

443. Proportions of Hydraulic Pipes.

For Accumulator pressure of 700 lbs. per square inch: Inside diameter (d) in inches $+ 2 =$ thickness of metal in $\frac{1}{8}$ths. Filling pipes made by local firms, $\frac{1}{16}$ inch thicker.

Flanges oval, $2\cdot85\ d \times 1\cdot55\ d$ and $\frac{1}{2}\ d$ thick, with 2 square-necked bolts each $\frac{1}{4}\ d$ in diam.

444. Thickness of Pipes for Hydraulic Accumulator Mains

For 700 lbs. per sq. in.

Armstrong .. .. $t = \frac{d}{8} + \cdot25$

Brown .. .. $t = \frac{d}{6}$.

445. Thickness of Pipes for Water Co.'s Mains.

For 200 feet head:

Hawksley $t = \cdot 18 \sqrt{d}$

Unwin $t = \cdot 11 \sqrt{d} + \cdot 1$

Box $t = \left(\frac{\sqrt{}}{10} + \cdot 15\right) + \left(\frac{d\mathrm{H}}{25000}\right)$

or say $= \frac{\sqrt{d}}{10} + \cdot 15 + \frac{d}{125}$

Molesworth $t = \cdot 000054\, \mathrm{H}\, d + x$

or say $= \cdot 0108\, d + \frac{\sqrt{d}}{10}$

446. General Rules for Thickness of Pipes.

Unwin $t = \cdot 5\, d \left(\sqrt{\frac{2775 + p}{2775 - p}} - 1\right)$

Barlow $t = \frac{\cdot 5\, d}{\frac{16000}{p} - 1} \times 5$ for safety.

Adams $t = \frac{d p}{6000} + \frac{\sqrt{p}}{100} + \frac{\sqrt{d}}{10}$ ($+ \cdot 125$ for steam).

Campin $t = \frac{p\, d}{6000} + \cdot 66.$

447. Notes on Pipes.

Iron, composition, and lead pipes are measured by their inside diameter, brass and copper pipes by their outside diameter.

Wrought iron pipes are bent by filling with sand and making red-hot, keeping the joint on the side of the bend.

448. Dr. Angus Smith's Composition for Coating Pipes.

Original recipe was 30 gallons coal tar, 30 lbs. fresh slaked lime, 6 lbs. tallow, 3 lbs. lampblack, 1½ lb. resin, to be well mixed, boiled 20 minutes and put on hot.

The modern practice varies, but a good mixture is 3½ barrels coal tar, ½ barrel coal oil, ½ barrel pitch, with six tons gas coke for heating pipes. Made and used as follows: Into a wrot. iron tank long enough to take a 9 ft. pipe, sufficient coal tar to half cover a pipe is put in, then pitch beaten to a powder, and sprinkled on the tar, and coal oil poured on the pitch. The pipes heated to 180° to 200°, or as hot as the hand can bear, are put into the liquid separately and turned over and over for 2 or 3 minutes, then placed at an angle to drain, with the lower end clear of the liquid. The above quantities will do about 1000 pieces, bends, branches and straight pipes, or say ¾ barrel coal tar to 100 9-feet lengths of 4-in pipes. This method avoids risk from the liquid catching fire.

449. Hydraulic Press with Hand-pump.

P = pressure in lbs. on handle of pump.
d = diam. of pump in inches.
l = effective leverage $= \dfrac{\text{power leverage}}{\text{resistance leverage}}$.
D = diam. of press in inches.
M = modulus or coefficient of press, say $= \cdot 8$
W = total load in lbs, or maximum effort of press.

$$W = P\, l \frac{D^2}{d^2} M.$$

Moseley ('Illustrations of Mechanics,' p. 197) says, "the discovery of it [the hydraulic press] is usually attributed to Pascal; it belongs, however, to the celebrated Stevin, mathematician to the Prince of Nassau, the inventor of decimals."

450. Hydraulic Press Cylinders.

d = diameter of ram in inches.
c = clearance between ram and cylr.
t = thickness of cylinder in inches.
p = pressure in lbs. per square inch.

$$t = \frac{d\,p}{2600} \qquad c = \frac{d}{12}.$$

Bottom hemispherical inside and out, except flat part outside to stand on, $= \frac{1}{2} d$ in diameter, and joined with easy radius.

Another rule:
P = bursting pressure in tons per square inch.
D = outside diam. in inches.
d = inside ,, ,,
T = maximum tensile strength per square inch of material.

$$P = T\,\frac{D^2 - d^2}{D^2 + d^2}.$$

451. Effective Pressure for Hydraulic Cranes and Hoists.

p = Accumulator pressure in lbs. per square inch.
m = ratio of multiplying power.
E = effective pressure in lbs. per square inch, including all allowances for friction.

$$E = p\,(\cdot 84 - \cdot 02\,m).$$

452. Diaphragm Regulator for Hydraulic Machinery.

When a hydraulic crane or hoist works too quickly, and it is desired to reduce the speed to a safe limit, it is usual to partially close the stop valve; but when there is a risk of this being interfered with, a brass diaphragm, $\frac{1}{8}$th diameter thick and about $\frac{1}{8}$-inch at edge, is placed in a pipe joint near the working valves. The hole in the diaphragm should be tapered, the small side being next to the machine.

To find size :—

A = area of lifting ram, square inches.
m = ratio of multiplying power.
s = speed of lifting chain with full load ft. per. sec.
p = accumulator pressure, lbs. square inch.
a = area of small side of hole (large side = twice diameter of small side).

$$a = \frac{A\,s}{6\,m\,\sqrt{1 \cdot 932\,p - \cdot 046\,m}}.$$

453. Power and Speed of Hydraulic Hauling Machines.

	Strain on Rope.	Hauling Speed, ft. per min.
Railway capstans	2000 lbs.	180
	2240 ,,	200
Barge ,, ...	1½ tons	120
Ship ,, ...	2½ to 5 ,,	80
Railway traversers ..	75 lbs. per ton of load.	
Lock gate machines ..	375 lbs. per foot width of entrance.	

454. Speed of Lifting with Hydraulic Power.

Warehouse cranes and jiggers 6 feet per second.

Platform cranes and small luggage lifts, 4 feet per second.

Passenger and waggon hoists, 2 feet per second.

Maximum speed under any circumstances, 10 feet per second.

General formula for warehouse cranes.

W = load in tons.
h = height of lift in feet.
v = velocity in feet per second.

$$v = \frac{h}{W + 10}.$$

455. Lifting Rams for Hydraulic Cranes.

W = load to be lifted in lbs.
w = weight of ram, crosshead, sheaves, and chain.
l = height of lift in feet.
m = multiplying power.
c = coefficient of effect = $\cdot 84 - \cdot 02\, m$.
a = area of ram in square inches.
s = stroke of ram in inches.
p = Accumulator pressure in lbs. per square inch.
C = capacity of cylinder in cubic feet.

For horizontal cylinders:—

$$a = \frac{W m}{p c}. \qquad C = \frac{W l}{144 p c}.$$

For vertical cylinders:—

$$a = \frac{W m + w}{p c}. \qquad C = \frac{W l + w s}{144 p c}.$$

For inverted cylinders:—

$$a = \frac{W m - w}{p c}. \qquad C = \frac{W l - w s}{144 p c}.$$

456. Turning Rams for Hydraulic Cranes.

W = load in tons.
R = rake in feet.
l = length between bearings in feet.
d = diameter of turning drum in feet.
p = Accumulator pressure, lbs. per square inch.
m = multiplying power of turning cylinder (usually 2 to 1).
a = area of turning ram in square inches.

Alternative formulæ:—

$$a = \frac{120\,W\,R^2\,m}{l\,d\,p}. \qquad a = \frac{3000\,W\,R\,m}{l\,d\,p}.$$

$$a = \left(5906\,\frac{W\,R\,m}{l\,d\,p}\right) - 3 \cdot 3.$$

457. Areas of Valves for Machinery under Accumulator Pressure.

A = area of lifting ram.
m = ratio of multiplying power.
v = velocity of load in feet per second.
V = velocity of water through valve, feet per second.
W = weight of ram, crosshead, sheaves, chain, &c., in lbs.
a = area of lifting valve (mitred spindle).
a^1 = area of lowering valve (mitred spindle).

$$a = \frac{A\,v}{m\,V} \qquad a_1 = \frac{A\,v}{m\sqrt{13 \cdot 8\,\frac{W}{A}}};$$

When cylinder is horizontal, then $\frac{W}{700}$ = area of returning ram.

458. Areas of Ports in Slide Valves.

v = velocity of load in feet per second.
m = ratio of multiplying power.
A = area of ram in square inches.

Area of pressure port $= \dfrac{A\,v}{98\,m}$ (opening side, V-shaped).

Area of exhaust port $= \dfrac{1 \cdot 5\,A\,v}{98\,m}$.

The dimensions of the slide should be such that the unbalanced pressure does not exceed 1000 lbs. per sq. in. on the net working surface of metal.

459. Counterweights for Crane Chains.

The overhauling weights should be oval, i.e. egg-shaped, with small end on top to avoid catching under beams, &c. Hole for chain should be $\frac{1}{8}$ inch larger than cross section of links, and interior should be cored out to $\frac{1}{4}$ inch clear all round. The approximate weight of counterbalance required is $\frac{1}{20}$th of the load.

460. Strain allowed on Wrought Iron in Hydraulic Cranes.

	Tons per square inch. Tension.	Tons per square inch. Compression.
Ballast and coaling cranes.. ..	$2\frac{1}{2}$	1
Warehouse and other cranes lifting from 1 to 5 tons	3	2
Cranes lifting more than 5 tons..	$3\frac{1}{2}$	3

461. Lock Gates.

The span of a pair of gates should form the diagonal of a square, the curve of the centre line of gates being struck from the opposite corner of the square, radius = length of side = ·707 span, giving angle of 136°, or rise of $\frac{1}{5}$ span.

The pressure of water per sq. ft. varies at different depths, being 62·5 × difference of head on the two sides at the point considered.

The hauling strain on gate chains averages 336 lbs. per ft. width of entrance, but in practice hydraulic and other machines are calculated for an effective strain on the chain of 375 lbs. per ft. width of entrance. The total weight of a pair of gates averages $2\frac{1}{2}$ tons per ft. width of entrance.

SECTION XIII.

ELECTRICAL ENGINEERING.

Note.—As this subject is not included in the Engineeing Course at the City of London College only a few brief notes have been given.

462. Electrical Terms.

An electric current flows in a battery from the *Positive* (or +) *plate* to the *Negative* (or −) *plate*, and outside the battery from the *positive pole* (connected to the − plate) to the *Negative pole* (connected to the + plate): If the *Electromotive force*, E.M.F. or *Potential difference* = 1 *Volt*, and the resistance through which the current flows = 1 *Ohm*, the strength of the current = 1 *Ampère*, the quantity

of electricity flowing per sec. = 1 *Coulomb*, and the work per sec. = 1 *Joule*. If it requires 1 coulomb of electricity to charge a condenser to a potential of 1 volt, the capacity of the condenser = 1 *Farad*. If the mean force of attraction between two opposite charges of electricity = 1 *dyne*, the work done per centimetre displacement = 1 *erg*. If electricity flows through any measuring instrument, the terminals at which it enters and leaves are *electrodes*; that at which the current enters = *anode*, that at which it leaves = *cathode*. A fluid decomposable by electricity is an *electrolyte*, the products of the decomposition are *ions*.

A volt is about 7 per cent. less than E.M.F. of Standard Daniell cell. An ohm is the resistance of a column of mercury 106·2 c.m. long × 1 sq. m.m. section, at 0° C. It is about the resistance of a pure copper wire $\frac{1}{20}$ inch diam. and 250 ft. long. The legal ohm = ·998 true ohm, B.A. ohm = ·9889 legal ohm = ·987 true ohm. One ampère deposits 1·118 milligrammes of silver per sec. The capacity of a knot (6080 ft.) of submarine cable is about $\frac{1}{3}$ of a micro-farad.

The prefix *meg.* multiplies the unit by one million, *micro* divides it by one million, *milli* divides it by one thousand.

The Board of Trade Commercial Unit = 1000 Watt hours = 1·34 H.P. working for an hour. —*C. E. Grove.*

463. Electrical Equations.

Ampères × volts = Watts
Joules × time = Watts
Coulombs per sec. = Ampères
Watts ÷ 746 = Effective H.P.
Coulombs ÷ volts = Farads
13825 g. ergs. = 1 ft. lb.

·7373 ft. lbs. per sec. = 1 Joule
Dyne = Unit force C.G.S. system
Work done by dyne = Centimetre-erg.
Volts × coulombs = Joules

464. Electric Lighting.

"To make the matter quite clear, let a practical illustration be taken. Let it be supposed that a house has to be lighted by a hundred incandescence lamps each requiring a current of ·75 of an ampère urged by an electromotive force of 100 volts. The rate at which energy is expended in each lamp, expressed in volt ampères or watts, of which 746 are equal to a horse-power, will be ·75 × 100, that is 75. The energy expended in the 100 lamps will be at the rate of 7500 watts, which are equal to 10·05 horse-power. But this, it must be remembered, is the actual rate at which energy is expended in the lamps. The energy that has to be developed by the engine is greater, for no dynamo-electric machine is perfectly efficient, no dynamo machine gives out as electrical energy the exact equivalent of the mechanical energy expended upon it. Let it be supposed that the machine used in our installation has a "commercial efficiency" of 80 per cent., that is that 80 per cent. of the mechanical energy put into the machine reappears in the external or lamp circuit as electrical energy, the balance being wasted in heating the armature coils, and the friction of axles, slipping of belts, and other mechanical sources of loss. Then the rate at which energy is generated by the steam engine must be 10·05 × 1·25, that is 12·55 horse-power. This mechanical energy is to be produced by the combustion of coal, and if all the heat liberated in the combustion of coal could be collected and utilised, the supply of coal required to generate energy at the rate of 12·55 horse-

power would be very small; but, unfortunately, steam engines even of the best make, have but low efficiency, and a horse-power-hour of energy requires in practice somewhere about 4½ lb. of coal for its production; 12·55 horse-power-hours will therefore require about 56½ lb. of coal—say, roughly, half a hundredweight, the cost of which is not more than 6*d*. Assuming that the lamps were required to burn for 1800 hours a year—that is, on an average, nearly 5 hours a day—the annual cost for coal would be 45*l*. The prime cost of a suitable dynamo machine and engine (with boiler) would be, say, 300*l*., the interest on which at 4 per cent. would be 12*l*., and the annual depreciation, at 10 per cent., 30*l*.; the cost of attendance would be about 60*l*,; so that the prime cost would be 300*l*., and the total annual cost 147*l*., or 1*l*. 9*s*. 5*d*. per lamp."—*Probert*, 1888.

Chief systems are:—

1. Alternating current—where the current flows in different directions—or the high tension system.

2. The continuous current, or low pressure, or storage system.

SECTION XIV.

SUNDRY NOTES AND TABLES.

465. Arithmetical Terms.

Item	Multiplicand
Item	Multiplier
Sum	Product.

Divisor) Dividend
Quotient.

$$\text{Fraction} = \frac{\text{Numerator}}{\text{Denominator}}$$

Types of Vulgar Fractions.

$$\tfrac{3}{16} \times 9 = \frac{3 \times 9}{16}, \qquad \tfrac{3}{4} \times \tfrac{5}{7} = \frac{3 \times 5}{4 \times 7}, \qquad \tfrac{2}{3} \div \tfrac{7}{11} = \frac{2 \times 11}{3 \times 7},$$

$$\tfrac{5}{6} \div 3 = \frac{\tfrac{5}{6}}{3} = \frac{5}{6 \times 3}, \qquad 3 \div \tfrac{5}{6} = \frac{3}{\tfrac{5}{6}} = \frac{3 \times 6}{5},$$

$$\frac{\tfrac{3}{4}}{\tfrac{5}{8}} = \frac{3 \times 8}{4 \times 5}, \qquad \tfrac{3}{8} \text{ of } 16 = \frac{16 \times 3}{8}, \qquad \frac{4 \times \tfrac{1}{5}}{7} = \frac{4}{5 \times 7},$$

$$\tfrac{4}{5} \text{ of } \tfrac{5}{7} = \frac{4 \times 5}{5 \times 7}, \qquad \frac{23\tfrac{4}{5}}{7} = \frac{(5 \times 23) + 4}{7 \times 5} = 3\tfrac{14}{35},$$

$$\tfrac{3}{5} + \tfrac{4}{7} = \left.\begin{matrix} 3 \times 7 = 21 \\ 5 \times 4 = 20 \end{matrix}\right\} 41 = \frac{41}{35}, \qquad \tfrac{3}{5} - \tfrac{4}{7} = \left.\begin{matrix} 3 \times 7 = 21 \\ 5 \times 4 = 20 \end{matrix}\right\} 1 = \frac{1}{35}.$$
$$5 \times 7 = 35 \qquad\qquad 5 \times 7 = 35$$

466. Ratio and Proportion.

The ratio of 1 to 2 is $\frac{1}{2}$ or $\cdot 5$; the ratio of a to b is the fraction $\frac{a}{b}$; or in other words the ratio between two quantities is the proportion the first bears to the second, and is represented by the first divided by the second, thus 1 is the $\frac{1}{2}$ of 2, and a is the $\frac{a}{b}$ of b.

467. Epitome of Mensuration.

a = area, b = base, p = perpendicular.
r = radius, d = diam., h = height.
n° = no. of degrees, c = circumference.

Rectangle or parallelogram. $a = bp$.

Trapezium (2 sides parallel). a = mean length par. sides $\times$ distance between them.

Triangle, $a = \frac{1}{2}\,bp$.

Irregular figure, a = wt. of template $\div$ weight of sq. in. similar material.

Circle, $a = \pi r^2 = d^2 \frac{\pi}{4} = \cdot 7854\, d^2$.

$c = 2\pi r = d\pi = 3\cdot 1416\, d = 3\cdot 54 \sqrt{a}$.

Side of equal sq. $= \cdot 8862\, d$.

„ inscribed sq. $= \cdot 7071\, d$.

$d = \cdot 3183\, c$.

Segment of circle.

Length arc $= \cdot 0174533\, n^\circ\, r$.

Approx. ditto $= \frac{1}{3}$ (8 times chord of $\frac{1}{2}$ arc $-$ chord whole arc).

Sector of circle.

$a = \cdot 5\, r \times$ length arc.

$a = n^\circ \times$ area circle $\div$ 360.

Ellipse. $a = \cdot 7854\, \mathrm{D}\, d$, $\quad c = \sqrt{\frac{\mathrm{D}^2 + d^2}{}} \times \pi$.

Cone or pyramid.

$$\text{Surface} = \frac{\text{circf. base} \times \text{slant length}}{2} \times \text{base}.$$

Contents = area base $\times \frac{1}{3}$ vert. height.

Sphere.

Surface $= d^2 \pi$, contents $= \cdot 5236\, d^3$.

Frustum of cone.

Contents $= D^2 + d^2 + 2\cdot 618\, D\, d\, h$.

Segment of sphere.

r = rad. of base, contents $= \cdot 5236\, h\, (3\, r^2 + h^2)$

Prismoidal formula.

$$\text{Contents} = \frac{\text{end areas} + 4 \text{ times middle area}}{6} \times \text{length}.$$

468. Colours used in Architectural and Mechanical Drawing.

Materials.	Elevation.	Section.
Wrought iron ..	Prussian blue, very pale	Prussian blue, dark.
Cast iron	Payne's grey „ „	Payne's grey „
Yellow brass ..	Gamboge	Gamboge „
Gun metal	Indian yellow	Indian yellow „
Steel	Violet carmine, very pale	Violet carmine „
Lead	Indigo, very pale	Indigo „
Zinc	French blue, very pale ..	French blue „
Leather	Burnt umber „ „ ..	Burnt umber „
Chain	Prussian blue, dot and stroke.	
Rope	Burnt sienna, dot and stroke.	
Copper	Crimson lake and burnt sienna.	Crimson lake and burnt sienna, dark.
Fir and deal	Burnt sienna, pale ..	Burnt sienna, dark.
Oak	Burnt umber „ ..	Burnt umber „
Brickwork	Roman ochre	Crimson lake „
Red bricks	Light red	Light red „
Soft stone	Sepia, very pale	Sepia „
Hard stone	Indigo „ „	Indigo „
Concrete		Payne's grey and sepia.
Earth	Ink stippling	Sepia, light and dark
Plaster and cement	Indian ink, pale	Indian ink, dark.
Slate	Payne's grey	Payne's grey „
Line of section ..	Vermilion, stroke and dot.	
Mahogany	Light red and burnt sienna.	Light red and burnt sienna, dark.
Greenheart	Indigo and gamboge ..	Indigo and gamboge, dark.
Old brickwork ..	Indian ink, pale	Indian ink, dark.
Blue bricks	Indigo and indian ink ..	Indigo „
Stone dressings ..	French blue, very pale ..	French blue „
Windows inside ..	Ditto, washed, pale ..	Hooker's green, No. 2, dark.
„ outside ..	Payne's grey, washed, dark.	Hooker's green, No. 2, dark.
Rain-water pipe ..	Prussian blue, outline.	
Soil pipe	Burnt sienna „	
Water	Prussian blue, washed ..	Prussian blue, lines.
Existing timber ..	Indian ink, pale	Indian ink, etched.

469. Composition of Colours for Drawings.

Usual colour.	Equivalent Mixtures.
Payne's grey	Indigo, indian ink, and crimson lake.
Burnt umber ..	Vandyke brown, or sepia, and burnt sienna.
Roman ochre	Yellow ochre, or pale burnt sienna and sepia.
Indian red	Light red.
Indian yellow ..	Gamboge and pale burnt sienna.
Violet carmine ..	Prussian blue and crimson lake.
Hooker's green ..	Prussian blue and gamboge.

470. Section Lines in Mechanical Drawing.

The sectional shading to indicate the materials should be as follows:—

Cast iron ..	thin lines at an angle of 45°.
Wrot. iron ..	alternate thick and thin do. do.
Brass	alternate thin and broken lines do.
Steel	all broken or dotted lines do.
Lead	thin lines at angle 60° in both directions.
Wood	rings and rays in imitation of grain.

471. Basis of French Measurements.

The mètre professes to be the one ten-millionth part of the quadrant of the meridian passing through France from Dunquerque to Formentera, but is actually the length, when at the temperature of melting ice, of a platinum rod made by Borda. The exact length is doubtful, viz:

French Academy	39·3827 inches.
Capt. Kater	39·37079 „
Mr. Hassler (U.S.)	39·3802 „
Ordnance Dept. Great Britain	39·37043196 „

472. French Measures.

1 Metre or 1 m. = 3·281 ft. say 3′ $3\frac{3}{8}''$

1 Decimetre or 1 dm. (very seldom used) = $3\frac{15}{16}''$ or nearly 4 inches.

1 Centimetre or 1 cm. or 1 c/m. = $\frac{3}{8}\ \frac{1}{64}''$ or say $\frac{3}{8}''$ full.

1 Millimetre or 1 mm. or 1 m/m. = $\frac{3}{64}''$ or about $\frac{1}{25}$th of an inch.

Millimetres per metre × ·012 = inches to 1 foot.

Weight in lbs. × ·45 = weight in kilos.

Metres per second × 3·281 = feet per second.

Do. × 196·85 = feet per minute.

Echelle = scale. Fraction thus $\frac{1}{250}$ gives proportion of drawing to real size.

For useful tables of comparisons see Brook's 'French Measures and English Equivalents.'

473. Nomenclature of Large Numbers.

	Billions.	Millions.	Thousands.	Units.
English	000,000	000,000	000	000

	Quadrillions.	Trillions.	Billions.	Millions.	Thousands.	Units.
French	000	000	000	000	000	000

474. Units employed in Engineering Calculations.

Dimensions in inches.

Loads or forces in lbs.

Stresses in lbs. per square inch.

Fluid pressure in lbs. per square inch.

Velocities and accelerations in feet per second.

Mechanical work in foot-lbs.

Speeds of rotation in revolutions per minute, or in angular velocity per second.

Statical moments (as bending and twisting moments) in inch lbs.—*Unwin's 'Machine Design.'*

475. Decimal Equivalents to Fractions of an Inch.

·96875	= $\frac{7}{8}+\frac{3}{32}$	·625	= $\frac{5}{8}$	·28125	= $\frac{1}{4}+\frac{1}{32}$
·9375	„ $\frac{7}{8}+\frac{1}{16}$	·59375	„ $\frac{1}{2}+\frac{3}{32}$	·25	„ $\frac{1}{4}$
·90625	„ $\frac{7}{8}+\frac{1}{32}$	·5625	„ $\frac{1}{2}+\frac{1}{16}$	·21875	„ $\frac{1}{8}+\frac{3}{32}$
·875	„ $\frac{7}{8}$	·53125	„ $\frac{1}{2}+\frac{1}{32}$	·1875	„ $\frac{1}{8}+\frac{1}{16}$
·84375	„ $\frac{3}{4}+\frac{3}{32}$	·5	„ $\frac{1}{2}$	·15625	„ $\frac{1}{8}+\frac{1}{32}$
·8125	„ $\frac{3}{4}+\frac{1}{16}$	·46875	„ $\frac{3}{8}+\frac{3}{32}$	·125	„ $\frac{1}{8}$
·78125	„ $\frac{3}{4}+\frac{1}{32}$	·4375	„ $\frac{3}{8}+\frac{1}{16}$	·09375	„ $\frac{3}{32}$
·75	„ $\frac{3}{4}$	·40625	„ $\frac{3}{8}+\frac{1}{32}$	·0625	„ $\frac{1}{16}$
·71875	„ $\frac{5}{8}+\frac{3}{32}$	·375	„ $\frac{3}{8}$	·03125	„ $\frac{1}{32}$
·6875	„ $\frac{5}{8}+\frac{1}{16}$	·34375	„ $\frac{1}{4}+\frac{3}{32}$	·015625	„ $\frac{1}{64}$
·65625	„ $\frac{5}{8}+\frac{1}{32}$	·3125	„ $\frac{1}{4}+\frac{1}{16}$	·0078125	„ $\frac{1}{128}$

476. Whitworth Standard Bolts and Nuts.

Vee threads 55°, $\frac{1}{6}$ depth rounded off top and bottom, depth = ·64 pitch, thickness of nut = diam. of bolt. Weight of head and nut = $1·07\,d^3$ for hexagon, or $1·35\,d^3$ for square.

Diam. bolt. Ins.	Threads per inch	Diam. bottom thread.	Area bottom thread.	Thickness head.	Diam. over flats.	Diam. over angles.	Diam. of tapping hole
$\frac{1}{2}$	12	·3932	·1215	·4375	·9191	1·0612	$\frac{7}{16}$
$\frac{5}{8}$	11	·5085	·2030	·5468	1·1010	1·2713	$\frac{1}{2}+\frac{1}{32}$
$\frac{3}{4}$	10	·6219	·3037	·6562	1·3012	1·5024	$\frac{5}{8}+\frac{1}{32}$
$\frac{7}{8}$	9	·7327	·4216	·7656	1·4788	1·7075	$\frac{3}{4}$
1	8	·8399	·5540	·8750	1·6701	1·9291	$\frac{7}{8}$
$1\frac{1}{8}$	7	·9420	·6969	·9843	1·8605	2·1483	$\frac{15}{16}+\frac{3}{64}$
$1\frac{1}{4}$	7	1·0670	·8941	1·0937	2·0483	2·3651	$1\frac{5}{64}$
$1\frac{1}{2}$	6	1·2865	1·2998	1·3125	2·4134	2·7867	$1\frac{5}{16}$
$1\frac{3}{4}$	5	1·4938	1·7525	1·5312	2·7578	3·1844	$1\frac{1}{2}+\frac{1}{32}$
2	4	1·7154	2·3110	1·7500	3·1491	3·6362	$1\frac{3}{4}$

Bright nuts approx. = $1\frac{1}{2}\,d$ over sides, $1\frac{3}{4}\,d$ over angles. No. of sq. threads = $\frac{1}{2}$ no. V threads. Approx. diam. washer = $\frac{1}{2}$ diam. bolt, or $\frac{1}{4}$ inch more than diam. over angles.

477. Whitworth Gas Threads.

Note.—Diameter of pipe is measured inside.

$\frac{1}{8}''$ diam. = 28 threads per in.
$\frac{1}{4}''$ to $\frac{3}{8}''$ „ = 19 „
$\frac{1}{2}''$ „ $\frac{3}{4}''$ „ = 14 „
$1''$ „ $4''$ „ = 11 „

478. British Association (B.A.) Gauge for Apparatus Screws.

This is adopted as the Standard Screw Gauge by the Post Office Telegraphs Department and most large electrical firms.

Number.	Nominal Dimensions in Thousandths of an Inch.			Absolute Dimensions in Millimetres.	
	Diameter.	Pitch.	Threads per inch.	Diameter.	Pitch.
25	10	2·8	353	0·25	0·072
24	11	3·1	317	0·29	0·080
23	13	3·5	285	0·33	0·089
22	15	3·9	259	0·37	0·098
21	17	4·3	231	0·42	0·11
20	19	4·7	212	0·48	0·12
19	21	5·5	181	0·54	0·14
18	24	5·9	169	0·62	0·15
17	27	6·7	149	0·70	0·17
16	31	7·5	134	0·79	0·19
15	35	8·3	121	0·90	0·21
14	39	9·1	110	1·0	0·23
13	44	9·8	101	1·2	0·25
12	51	11·0	90·7	1·3	0·28
11	59	12·2	81·9	1·5	0·31
10	67	13·8	72·6	1·7	0·35
9	75	15·4	65·1	1·9	0·39
8	86	16·9	59·1	2·2	0·43
7	98	18·9	52·9	2·5	0·48
6	110	20·9	47·9	2·8	0·53
5	126	23·2	43·0	3·2	0·59
4	142	26·0	38·5	3·6	0·66
3	161	28·7	34·8	4·1	0·73
2	185	31·9	31·4	4·7	0·81
1	209	35·4	28·2	5·3	0·90
0	236	39·4	25·4	6·0	1·00

479. Birmingham Wire Gauge.

(Till 1st March, 1884).

No.	Parts of an inch.	No.	Parts of an inch.	No.	Parts of an inch.
5/0	= 0·500	9	= 0·148	22	= 0·028
4/0	454	10	135	23	025
3/0	425	11	120	24	0220
2/0	380	12	109	25	0200
0	340	13	095	26	0180
1	300	14	083	27	0160
2	284	15	072	28	0140
3	260	16	065	29	0130
4	238	17	058	30	0120
5	220	18	050	31	0100
6	203	19	041	32	0090
7	180	20	035	33	0080
8	165	21	032		

This is now obsolete, but is still frequently specified as No. —— B.W.G.

480. Standard Sheet and Hoop-iron Gauge (B.G.).

(From March 1st, 1884).

No. of Gauge	Thickness in — Ordinary Fractions of an inch.	Thickness in — Decimals of an Inch.	Thickness in — Millimetres.	Approximate Weight per superficial foot of Sheet Iron in pounds.
3°	$\frac{1}{2}$	·500	12·700	20·
2°	..	·4452	11·288	17·808
1°	..	·3064	10·068	15·856
1	..	·3532	8·971	14·128
2	..	·3147	7·993	12·588
3	..	·2804	7·122	11·216
4	$\frac{1}{4}$	·250	6·350	10·
5	..	·2225	5·651	8·90
6	..	·1981	5·032	7·924
7	..	·1764	4·480	7·056
8	..	·1570	3·988	6·28
9	..	·1398	3·551	5·592
10	$\frac{1}{8}$	·1250	3·175	5·
11	..	·1113	2·827	4·452
12	..	·0991	2·517	3·964
13	..	·0882	2·240	3·528
14	..	·0785	1·994	3·14
15	..	·0699	1·775	2·796
16	$\frac{1}{16}$	·0625	1·587	2·50
17	..	·0556	1·412	2·224
18	..	·0495	1·257	1·98
19	..	·0440	1·118	1·76
20	..	·0392	·996	1·568
21	..	·0349	·886	1·396
22	$\frac{1}{32}$	·03125	·794	1·25
23	..	·02782	·707	1·1128
24	..	·02476	·629	·9904
25	..	·02204	·560	·8816
26	..	·01961	·498	·7844
27	..	·01745	·4432	·698
28	$\frac{1}{64}$	·015625	·3969	·625
29	..	·0139	·3531	·556
30	..	·0123	·3124	·492
31	..	·0110	·2794	·440
32	..	·0098	·2489	·392
33	..	·0087	·2210	·348
34	..	·0077	·1956	·300
35	..	·0069	·1753	·276
36	..	·0061	·1549	·244
37	..	·0054	·1371	·216
38	..	·0048	·1219	·192
39	..	·0043	·1092	·172
40	..	·00386	·0980	·1544

481. Imperial Standard Wire Gauge.

Table of sizes, weights, lengths, and breaking strains of iron wire under the Imperial Standard Wire Gauge issued by the Iron and Steel Wire Manufacturers' Association.

(In force from March 1, 1884).

Size on Wire Gauge.	Diameter.		Sectional Area in sq. inches.	Weight of		Length of cwt.	Breaking Strain.	
	Inch.	Millemetres.		100 yards.	Mile.		Annealed.	Bright.
				lb.	lb.	yards.	lb.	lb.
7/0	0·500	12·7	0·1963	193·4	3404	58	10470	15700
6/0	0·464	11·8	0·1691	166·5	2930	67	9017	13525
5/0	0·432	11	0·1466	144·4	2541	78	7814	11725
4/0	0·400	10·2	0·1257	123·8	2179	91	6702	10052
3/0	0·372	9·4	0·1087	107·1	1885	105	5796	8694
2/0	0·348	8·8	0·0951	93·7	1649	120	5072	7608
1/0	0·324	8·2	0·0824	81·2	1429	138	4397	6595
1	0·300	7·6	0·0707	69·6	1225	161	3770	5655
2	0·276	7	0·0598	58·9	1037	190	3190	4785
3	0·252	6·4	0·0499	49·1	864	228	2660	3990
4	0·232	5·9	0·0423	41·6	732	269	2254	3381
5	0·212	5·4	0·0365	34·8	612	322	1883	2824
6	0·192	4·9	0·0290	28·5	502	393	1544	2316
7	0·176	4·5	0·0243	24	422	467	1298	1946
8	0·160	4·1	0·0201	19·8	348	566	1072	1608
9	0·144	3·7	0·0163	16	282	700	869	1303
10	0·128	3·3	0·0129	12·7	223	882	687	1030
11	0·116	3	0·0106	10·4	183	1077	564	845
12	0·104	2·6	0·0085	8·4	148	1333	454	680
13	0·092	2·3	0·0066	6·5	114	1723	355	532
14	0·080	2	0·0050	5	88	2240	268	402
15	0·072	1·8	0·0041	4	70	2800	218	326
16	0·064	1·6	0·0032	3·2	56	3500	172	257
17	0·056	1·4	0·0025	2·4	42	4667	131	197
18	0·048	1·2	0·0018	1·8	32	6222	97	145
19	0·040	1	0·0013	1·2	21	9333	67	100
20	0·036	0·9	0·0010	1	18	11200	55	82

APPENDICES.

APPENDIX I.

Syllabus of City and Guilds of London Technical Institute in

(10). Iron and Steel Manufacture.
(22). Electrical Engineering.
(23). Metal Plate Work.
(27). Tools.
(28). Mechanical Engineering.

10.—IRON AND STEEL MANUFACTURE.

I. Syllabus.—The Examination will include questions founded on such subjects as the following:—

1. Composition and general characters of the chief iron ores. Preparation of raw ores for smelting; changes in composition thereby produced.
2. Construction and mode of working of blast furnaces, and subsidiary appliances.
3. Nature of fluxes requisite under various conditions. Utilisation of blast-furnace cinder, and of forge and mill cinder in the blast-furnace.
4. Hot and cold blast; effects of these and of variations in amount of fuel and flux, and in their nature, on the production and character of the iron made.
5. Characters of pig iron from various kinds of ore; general effects of foreign elements on these characters. Production of spiegeleisen and ferromanganese.
6. General chemical and physical distinctions between pig iron, wrought iron, and steel. Modern classification of iron and steel.
7. Methods of casting iron and steel. Foundry appliances and operations. Furnaces, crucibles, and moulds, &c., requisite for large steel castings. Malleable iron castings; chilled castings.
8. Conversion of pig iron into malleable iron; refining, puddling, and boiling; fettling, and its uses; hand and machine puddling. Machinery and appliances requisite, such as shingling helves and hammers, and hydraulic forging machinery, squeezers, steam-hammers, rolling mills, and their respective advantages and disadvantages. Manufacture of bars, plates, rods, rails, tyres, hoops, wire, cold rolled shafting, &c.
9. Conversion of malleable iron into steel. Blister, shear, and cast steel. The effects of the presence of carbon, silicon, phosphorus, sulphur, and manganese.

10. Conversion of pig iron into steel. Puddled steel. Acid and basic Bessemer processes. Acid and basic open hearth processes, and other analogous special processes.

11. Production of steel direct from the ore without the use of the blast-furnace. Catalan forge, Wootz, Chenot, Siemens, and other analogous processes.

12. Machinery and appliances requisite for manufacture of cast steel, Bessemer steel, and other kinds of steel largely used, including steel-compressing machinery.

13. The variations occurring in the qualities of different kinds of steel, the causes of these variations, and the methods by which the various sources of imperfection may be best avoided or overcome.

14. The nature of the physical and chemical tests of the qualities of iron and steel, and the effects on these qualities of foreign élements. Comparative strength of iron and steel.

15. Hardening and tempering of steel, including the use of oil, water, and cold surfaces; precautions to be used in re-heating large masses of steel to avoid fracture. General principles involved.

16. Case-hardening.

17. Welding of iron and steel. Conditions requisite to produce good welds.

18. General nature of the leading chemical and physical changes occurring during the smelting of pig iron, its conversion into malleable iron, and the production of steel of various kinds.

19. Machinery for cutting, shaping, and working wrought iron.

20. Preparation of tin and terne plates, and of galvanised iron sheets, plain and corrugated.

II. Full Technological Certificate.—The candidate who is not otherwise qualified (see Regulations 36, 37 and 38) will be required, for the full Certificate in the Ordinary Grade, to have passed the Science and Art Department's Examination, in the Elementary Stage at least, and for the full Certificate in the Honours Grade, in the Advanced Stage at least, in *two* of the following Science subjects:—

II. Machine Construction and Drawing.	VII. Applied Mechanics.
VI. Theoretical Mechanics.	X. Inorganic Chemistry.
	XIX. Metallurgy.

III. Works of Reference:—In addition to the ordinary text-books on the metallurgy of iron and steel, students should consult the article "Iron" in the "Encyclopædia Britannica," and should especially refer to the "Journal of the Iron and Steel Institute" for accounts of new processes and inventions, and experimental researches and trials, &c., published since the formation of the Institute, whereby much valuable practical information may be obtained. Much valuable information may also be gained from the transactions of the Institute of Civil Engineers, and the American Institute of Mining Engineers.

22.—ELECTRICAL ENGINEERING.

22A.—TELEGRAPHY.

I. Syllabus.—The Examination will include questions founded on such subjects as the following:—

1. The fundamental principles of electricity in their application to Electrical Engineering industries.
2. Units of Measurement. Practical standards of comparison.
3. The instruments necessary for the equipment of an Electrical Testing Room.
4. Electrical testing as applied to the inspection of apparatus, and to the detection and removal of faults.
5. The materials used in the construction of lines of telegraph.
6. The various systems of telegraphy.
7. Faults; their nature and prevention.
8. The application of electricity to railway working.
9. Earth currents, and electrical disturbances generally.
10. The various modes of testing materials.
11. The various systems in use to increase the capacity of wires for the conveyance of messages.
12. The construction of submarine cables; their laying and repair.
13. The reproduction of speech by electricity.

In the Honours Examination more difficult questions will be set in the preceding sections, and especially on the subjects included in sections 10 to 13.

II. Full Technological Certificate.—The Candidate who is not otherwise qualified (see Regulations 36, 37 and 38) will be required, for the full Certificate in the Ordinary Grade, to have passed the Science and Art Department's Examination, in the Elementary Stage at least; and for the full Certificate in the Honours Grade, in the Advanced Stage at least, in *two* of the following Science subjects:—

V. Mathematics.	VIII. Sound, Light and Heat.
VI. Theoretical Mechanics.	IX. Magnetism and Electricity.
VII. Applied Mechanics.	X. Inorganic Chemistry.

III. Works of Reference:—Culley's "Handbook of Telegraphy"; Thompson's "Electricity and Magnetism"; Fleeming Jenkin's "Electricity"; Preece and Sivewright's "Textbook of Telegraphy" (Longmans); Preece and Maiers, "The Telephone" (Whittaker); Langdon's "Application of Electricity to Railway Working" (Macmillan); Kempe's "Handbook of Electrical Testing" (Spon). Munro and Jamieson's "Electrical Engineering Rules."

22B.—ELECTRICAL LIGHTING AND TRANSMISSION OF POWER.

I. Syllabus.—In addition to the subjects included in Sections 1 to 4, **22A** (*see above*), the examination in Electric Lighting, &c., will include questions founded on such subjects as the following:—

5. Modes of generating an electric current for electric lighting or transmission of power. Dynamo machinery in its various forms.

6. Theoretical principles of a dynamo-electric machine. Continuous and alternate current machines.

7. Electric lamps, arc and incandescent, photometry, relative efficiency. electrical measurement of energy and current consumption.

8. Practical methods of arranging lamps and circuits.

9. Secondary and primary batteries. Construction, principles and uses.

10. Secondary generators. Structure and utility in distribution.

11. Electric motors. Theory of transmission of energy by electric methods

12. Characteristic curves, and graphic methods of delineating electrical behaviour of dynamos and motors.

13. Instrumental means for measuring electric currents and electromotive forces. Quantity meters, energy and Watt meters.

14. Methods of measuring electrical efficiency of dynamos and electro motors.

15. General principles of electric locomotion and transmission of power.

In the Honours Examination, more difficult questions will be set in the above subjects, especially in sections 9 to 15, and in addition a knowledge will be required of—

1. Theory of electric measurement in absolute methods. C.G.S. system. Determination of practical units.

2. The laws of dissipation of energy in conductors, and relation of sizes of conductors to currents to be transmitted.

3. The principal methods of central station distribution of electric current for lighting purposes.

4. General theory of alternating current dynamos and motors, and applications of alternating currents in lighting and other purposes.

II. Full Technological Certificate.—The Candidate who is not otherwise qualified (see Regulations 36, 37 and 38) will be required, for the full Certificate in the Ordinary Grade, to have passed the Science and Art Department's Examination, in the Elementary Stage at least; and for the full Certificate in the Honours Grade, in the Advanced Stage at least, in *two* of the following Science subjects:—

II. Machine Construction and Drawing.
V. Mathematics.
VI. Theoretical Mechanics.
VII. Applied Mechanics.
VIII. Sound, Light and Heat.
IX. Magnetism and Electricity.

III. Works of Reference.—"Short Lectures to Electrical Artizans," by J. A. Fleming (Spon); "Electricity," by Fleeming Jenkin (Longmans); "Dynamo-Electric Machinery," by S. P. Thompson (Spon); "Elementary Lessons in Electricity," by S. P. Thompson; "Electric Transmission of Energy," by Kapp (Whittaker); "Pocket-book of Electrical Formulæ," by Jameson & Munro (Griffin & Co.); "The Alternate Current Transformer in Theory and Practice,"; by J. A. Fleming, the "Electrician" Office, 1, Salisbury Court, Fleet Street; "Absolute Measurements in Electricity and Magnetism," by A. Gray (Macmillan); "Units and Physical Constants," by Everett. "Handbook of Electrical Testing," by Kempe (Spon); "Modern Views on Electricity," by O. J. Lodge (Macmillan); "Journal of the Institution of Electrical Engineers," 1878–1889; "Proceedings of the Institution of Civil Engineers"; "Practical Electricity," Ayrton (Cassell & Co), and "Elementary Practical Physics," Stewart and Gee (Macmillan); "Storage of Electrical Energy," Planté, translated by Ewell (Whittaker).

22C.—ELECTRICAL INSTRUMENT MAKING.

I. Syllabus.—In addition to the subjects included in Sections 1 to 4 **22A** (*see above*), the examination in Electrical Instrument Making will include questions founded on such subjects as the following:—

5. Detailed construction of permanent magnets. Composition of steel employed, mode of tempering and of magnetising.
6. Designing of electro-magnets. Shape to give to the core. Length and gauge of wire to be employed to fulfil a given specification.
7. Designing of galvanometers. (*a*) Absolute. (*b*) Sensitive. (*c*) Dead beat. (*d*) Astatic. (*e*) Differential. (*f*) For strong currents.
8. Construction of ordinary shunts, constant-current shunts. Keys and switches combining high insulation with economy in construction.
9. The practical construction of resistance coils; gauge of wire to be employed, modes of insulating, winding. Cheap accurate resistance coils. Standard coils.
10. Construction of condensers and artificial submarine cables; materials employed. Adjusting, testing.
11. Induction-coils. Length of spark obtainable. Precautions to be adopted to secure high insulation. Use of condenser with primary or with secondary coil.
12. Electroscopes; objection to form usually made. Improved forms. Construction of electrometers, electrical machines.
13. Designing of statical apparatus on scientific principles for teaching and laboratory use.

In the Honours Examination more difficult questions will be set in the above subjects, especially in those included in Sections 10 to 13, and, in addition, a knowledge will be required of:—

1. The general qualities of materials used for Insulation and Con-

duction and the mode of selection and specification for particular work.

2. The Construction of Standards for practical purposes according to special specification.

II. Full Technological Certificate.—The Candidate who is not otherwise qualified (see Regulations 36, 37 and 38) will be required, for the full Certificate in the Ordinary Grade, to have passed the Science and Art Department's Examination, in the Elementary Stage at least, and for the full Certificate in the Honours Grade, in the Advanced Stage at least, in *two* of the following Science subjects :—

II. Machine Construction and Drawing.
V. Mathematics.
VI. Theoretical Mechanics.
VII. Applied Mechanics.
IX. Electricity and Magnetism.

III. Works of Reference :—Fleeming Jenkin's "Electricity"; Cumming's "Electricity"; Du Moncel's "Applications d' Electricité" "Schwendler's "Testing Instructions"; Wiedemann's "Galvanismus"; Reports of the Paris Electrical Congress; Electrical Periodicals. "The Eectrician's Pocket-Book," by G. Wigan, M.A. (Cassell & Co); "Practical Electricity," Ayrton; "Practical Physics," Stewart and Gee (Macmillan).

23.—METAL PLATE WORK.

The Examination in the Ordinary Grade will consist of a paper of questions only.

I. Syllabus.—The Examination will include questions founded on such subjects as the following :—

1. The physical and chemical properties of iron, lead, antimony, bismuth, mercury, tin, zinc, copper, nickel and silver.
2. Alloys. The composition and properties of brass, bronze, tinplate, galvanised iron, &c. Tinning processes.
3. Solders and soldering. Composition and use of various solders. Theory and practice of soldering. Brazing. Autogenous soldering. Fluxes.
4. Fuel: composition and physical character of various kinds, and the modes of applying them in metal plate work.
5. The cutting of patterns for metal plate work of simple design.
6. The various tools used in metal plate work. Machinery for cutting and shaping metal plates.
7. Methods of joining sheet metal. Seaming, riveting, &c. Covering roofs.
8. Making sheet metal pipes, bends, elbows, &c.

It is important that Candidates should acquire facility in the production of clear and neat working drawings.

HONOURS GRADE.

Candidates for Honours must have passed in a previous year in the Ordinary Grade.

In the Examination for Honours—

1. More difficult questions will be set, founded on the above syllabus.
2. Working drawings to scale of a more advanced character will be required.
3. Each Candidate will also be required to execute in suitable material, in the year preceding the Examination, an original piece of work, and to forward the same to London (carriage paid) a fortnight prior to the date of the written Examination. The specimen of work must be accompanied by a working drawing with particulars of the quantity and nature of the materials used, and must be of such dimensions that it can fit into a box not larger than 15 × 12 × 12 ins. A certificate signed by the Candidate's employer, or by the class teacher and a member of the School Committee, stating that the work has been executed by the Candidate himself, without assistance, *must be forwarded with the specimen.* The work should be such as will show the Candidate's skill in the more important branches of metal work in which he is engaged.

II. Full Technological Certificate.—The Candidate who is not otherwise qualified (see Regulations 36, 37 and 38) will be required, for the full Certificate in the Ordinary Grade, to have passed the Science and Art Department's Examination in the Elementary Stage at least; and for the full Certificate in the Honours Grade, in the Advanced Stage at least, in *two* of the following Science subjects :—

I. Practical, Plane and Solid Geometry.	VII. Applied Mechanics.
II. Machine Construction and Drawing.	X. Inorganic Chemistry.
VI. Theoretical Mechanics.	XIX. Metallurgy.

Certificates showing that the Candidate has passed the Second Grade Examination of the Science and Art Department in Geometrical Drawing, as well as in Freehand or Model Drawing, will be accepted in lieu of one of the above Science subjects for the full Technological Certificate in either grade of the Examination.

III. Works of Reference :—Byrne, "Practical Metal-Worker's Assistant" (Philadelphia); "Miller's Chemistry," vol. ii.; Bloxam and Huntington, "Metals" (Longman, Green & Co.); Davidson, "Drawing for Metal Plate Workers" (Cassell & Co.); "Metal Plate Work" C. T. Millis (Spon).

27.—TOOLS.

27a.—WOOD-WORKING TOOLS.

I. Syllabus.—The Examination will include questions founded on such subjects as the following:—

Straight and Curved Works.—(*a.*)

1. The principles determining the forms, construction and cutting angles of axes, boring tools, chisels, planes, saws, and other hand-tools for works mostly rectilinear.
2. Work-benches and appliances as aids to accuracy. Tools for fixing, cramps, cauls, &c.
3. Manipulation of the hand-tools in the practice of the carpenter and joiner, carver, pattern-maker, &c. Inlaying, veneering, buhl cutting, parquetry, &c.
4. Grinding and setting wood-working tools, grindstones. Abraivse and miscellaneous processes for wood.
5. Planing, moulding, mortising, sawing, and other wood-working machines for joinery.
6. Hand-tools used in the sawpit. The methods followed to convert the log or butt. Circular and reciprocating saw-machines for cutting timber from the log. Machines for cutting veneers, &c.

Turning.—(*b.*)

1. The forms, differences, and cutting angles of the tools for soft wood, hard wood, and ivory turning, and their manipulation.
2. Plain lathes for wood turning. Chucks and appliances employed for mounting the rough material and partially-finished work, axial and eccentric, and precautions followed in chucking.
3. Gauges and other measuring tools. Turning in fac-simile. Turning the accurate sphere with the hand-tools.
4. Screw-boxes, Screw-cutting with the hand-tools in the lathe. Traversing maudrel. Methods of producing spiral balusters and coarse screws for ornament. Fluted and other ornament on straight and curved forms.
5. Chucks and tools employed in oval turning.
6. Turning or copying machines for producing numbers of the same object, such as spokes, lasts, gun-stocks, &c.

27b.—METAL-WORKING TOOLS.

Straight and Curved Works.—(*a.*)

1. The tools and appliances used in hand-forging. The tilt hammer and other simple contrivances for analogous purposes. Machines and apparatus for forging and stamping small works.
2. Manipulation in forging; various methods of producing the same form, and the particular application of the tools in these cases.

3. The different qualities and treatment of iron and steel used in the manufacture of edge tools. Annealing, hardening and tempering, and case-hardening. Preparation of the different metals to be wrought by the file, turning-tool, &c.

4. Brass and iron founding. Materials, tools and appliances used in moulding. Cores, &c.

5. Abrasive tools and processes. Those employed for reduction to form in the manufacture of edge-tools, saws, &c. Grinding and setting the cutting edges of tools for metal.

6. Files—their forms, manufacture, purposes, and manipulation. Other tools used to assist the file. Planing, slotting, and other machines for straight works.

7. Straight-edges, surface-plates, and other tests and gauges; their use and production. Measuring machines (Whitworth, &c.).

Turning.—(*b.*)

1. The forms and cutting angles of hand-turning tools for steel, iron, and brass. Tools for the slide-rest. planing-machine, &c. Drills and boring bars. Tool holders (sling tools).

2. Lathes for metal turning. Various methods by which different works are chucked or mounted in the lathe, and their relative advantages.

3. Manipulation in turning and boring works in metal. Sequence of the tools, and tests for accuracy in results.

4. Tools and materials employed to follow the turning tools in finishing and polishing, &c. Spinning on the lathe.

5. Striking and chasing screws by hand. Screw plates. Taps and dies. Screws cut in the traversing lathe.

6. Traversing and power lathes. Driving gear. The slide-rest. Guide screw and change wheels for plain turning and screw cutting. Rose engines, &c.

7. The division plate and index. Dividing engines attached to the mandrel or separate scribing tools. Forms and purposes of circular cutters, their construction; milling machines, &c. Stone-working tools. Watchmakers' "turns," &c.

II. Full Technological Certificate—The Candidate who is not otherwise qualified (see Regulations 36, 37 and 38) will be required, for the full Certificate in the Ordinary Grade, to have passed the Science and Art Department's Examination in the Elementary Stage at least; and for the full Certificate in the Honours Grade, in the Advanced Stage at least, in *two* of the following Science subjects:—

I. Practical, Plane, and Solid Geometry.
II. Machine Construction and Drawing.
VI. Theoretical Mechanics.
VII. Applied Mechanics.
XIX. Metallurgy.

III. Works of Reference.—Spretson's "Casting and Founding;" Knight's "Mechanician;" Holtzapffel's "Turning and Mechanical Manipulation;" Rose's "Pattern Makers' Assistant;" "Workshop Appliances," by C. P. B. Shelley; "Tools," by the Rev. A. Rigg (Cantor Lectures); Professor Smith's "Cutting Tools" (Cassell & Co.)

28.—MECHANICAL ENGINEERING.

I. Syllabus.—The Examination will include questions founded on such subjects as the following:—

1. Practical shop-work and processes. Operations of tempering, welding, riveting, etc. Pattern making, moulding and foundry work. The use of the ordinary machines of an engineer's shop. Fitting-shop work, including scraping and the use of gauges. Marking off. Erecting.

2. The steam engine and boiler, stationary, marine and locomotive: general questions as to design, arrangement, management and working. The construction and use of the most common engine and boiler fittings, including the steam engine indicator.

3. Pumps and pumping engines, including the Cornish engine. Pump valves. Centrifugal pumps and turbines. Water-pressure engines and hydraulic machinery in general.

4. The design and proportion of the simpler machine details, including the making of free-hand dimensioned sketches, roughly to scale. Mechanisms—means of obtaining and transmitting special motions in machinery. Spur and other forms of toothed gearing.

5. The strength and other properties of the principal materials used in engineering:—cast and wrought iron and steel, gun-metal, brass, etc. Elementary consideration of the strength of ties, struts, shafts and beams, and the methods of coupling or joining most suitable for each case. Ordinary shop tests for the strength and quality of materials.

In the Honours Examination, more difficult questions will be set in the above subjects, and, in addition, a knowledge will be required of:—

1. The use of such machines as multiple drills, milling machines, grinders for twist drills, etc. The making of standard planes and gauges. The setting of slide and expansion valves.

2. The (elementary) theory of the steam-engine, the expenditure of heat in the engine and economy of steam. Reversing gear. Brakes and dynamometers. Steam traps. The taking and interpretation of indicator cards. Gas engines.

3. Screw propellers and paddle wheels.

4. Friction and lubrication. The determination of the path in which any point in a machine is moving, its velocity relatively to other points of the machine, etc. The balance of forces in machines.

5. The modulus of elasticity and calculations involving its use. Stress and strain diagrams. Testing machines.

II. Care will be taken that the examination shall be of such a nature as to be passed by an intelligent workman at any mechanical engineering trade, who, with some knowledge of the science subjects mentioned below, has really studied and read books relating to his trade.

Candidates are expected to show a competent knowledge in at least three out of the five sections.

Special attention should be given to the making of clear, well-proportioned free-hand sketches, wherever these may be required, especially in Section 4.

III. Full Technological Certificate.—The Candidate who is not otherwise qualified (see Regulations 36, 37 and 38) will be required for the full Certificate in the Ordinary Grade, to have passed the Science and Art Department's Examination in the Elementary Stage at least; and for the full Certificate in the Honours Grade, in the advanced Stage at least, in *two* of the following Science subjects :—

I. Practical, Plane and Solid Geometry.	VI. Theoretical Mechanics.
II. Machine Construction and Drawing.	VII. Applied Mechanics.
V. Mathematics.	X. Inorganic Chemistry.
	XIX. Metallurgy.
	XXII. Steam.

IV. Works of Reference.—Shelley's "Workshop Appliances" (Longmans); R. H. Smith's "Cutting Tools" (Cassell); Perry's "Practical Mechanics" (Cassell); Fairbairn's "Mills and Millwork" (Longmans); Northcott's "Steam Engine" (Cassell); Cotterill's "Steam Engine" (Spon); Seaton's "Manual of Marine Engineering" (Griffin); Wilson's "Steam Boilers" (Crosby Lockwood and Son, London); Macgreger's "Gas Engines" (Symons); Magnus's "Hydrostatics"; Unwin's "Machine Design" (Longmans); Reuleaux's "Kinematics of Machinery" (Macmillan); Kennedy's "Lectures on Kinematic Models" (Macmillan); Anderson's "Strength of Materials" (Longmans); Jamieson's "Steam Engine" (Griffin).

APPENDIX II.

SYLLABUS OF GOVERNMENT DEPARTMENT OF SCIENCE AND ART IN

(II.) Machine Construction and Drawing.
(VI.) Theoretical Mechanics.
(VII.) Applied Mechanics.
(XXII.) Steam.

Subject II.—MACHINE CONSTRUCTION AND DRAWING

It is assumed that the student has already learned to draw to scale, and that he can draw two or more views of the same object in simple or orthographic projection. To pass in machine construction and drawing, he must be able to apply this knowledge to the representation of machinery. He must be acquainted with the form and purpose of the simpler parts of which machines are built up, and must have had some practice in drawing them. To test his knowledge, rough dimensioned sketches, more or less incomplete, of simple machine details will be given him, and he will be required to produce a complete drawing in pencil to a given scale. Two or more views of at least one subject will be required, and these must be so drawn as to be properly projected one from the other, in order to show that the student appreciates that he is producing a representation of a solid piece of machinery, and not merely copying a sketch. No credit will be given unless some knowledge of projection is shown. The centre lines of the drawings should be shown, and parts cut by planes of section should be indicated by diagonal shading. Bolts and other fastenings should be carefully shown where required. Any indication that a candidate has merely copied the sketches given, without understanding the part represented, will invalidate his examination.

FIRST STAGE, OR ELEMENTARY COURSE.

In the elementary stage, a knowledge is required of the simple parts only of machines in common use. Some of these are enumerated in the following list. The student should be practised in drawing them till he recognises their forms, and the object of the arrangement should be explained to him. He should also know the simple technical terms used in describing them.

A few very simple questions relating to the arrangement, proportions, and strength of the simplest machine details will be set in the examination paper.

In drawing the examples set to test a student's knowledge and skill in machine drawing, it must be remembered that only a limited time is available. It is only possible to set an example to be drawn in pencil, and the points which will receive attention, are: (1) accuracy of scale and projection; (2) power of reading a drawing, shown by the ability to transfer portions of the mechanism and dimensions from one view to another; (3) knowledge of machines as shown by the ability to fill in small details, such as nuts, keys, &c., omitted in the sketches given. Bearing in mind the limited time available, the student should try to make his outline clear and decisive and complete. But the diagonal lines necessary for sectional parts may be done rapidly, though neatly, by freehand if necessary.

Riveted Joints.—Forms of rivets and arrangement of rivets in lap and butt joints with single and double-riveting. Junction of plates by angle and T-irons.

Bolts, Studs, and Set-Screws.—Forms of these fastenings. Forms and proportions of nuts and bolt-heads. Arrangement of flanges for bolting.

Pins, Keys, and Cotters.—Form of ordinary knuckle joint. Use of split pins. Connection of parts by a key. Connection of parts by a cotter. Gib and cotter.

Pipes and Cylinders.—Forms of ordinary pipes and cylinders and their flanges and covers.

Shafting.—Forms of shafts and axles, and of journals and pivots. Use of collars and bosses. Half-lap coupling. Box coupling. Flange coupling.

Pedestals and Plummer Blocks.—Simplest forms of pedestals and hangers for shafts. Form and arrangement of brass steps. Arrangements for fixing pedestals and for neutralising the effects of wear.

Toothed Gearing.—Forms of ordinary spur and bevel wheels. Meaning of the terms pitch, breadth of face, thickness of tooth, pitch line, rim, nave, arm. Mode of drawing bevel wheels in section.

Belt Pulleys.—Forms of belt pulleys for flat and round belts. Stepped speed cones. Drawing of pulleys with curved arms.

Cranks and Levers.—Forms of ordinary cast-iron and wrought-iron cranks and levers. Modes of fixing crank pin. Modes of fixing crank shaft. Double cranks. Form of eccentrics.

Links.—Most simple forms of connecting rod ends, open or closed. Use of steps in connecting rods. Use of cotters to tighten the steps.

Pistons.—Simple forms of piston. Use of piston packing. Modes of attaching piston rod.

Stuffing Boxes.—Simple form of stuffing box and gland. Use of packing. Mode of tightening gland.

Valves.—Simple conical or puppet valve. Simple slide valve. Cock or conical sliding valve.

SECOND STAGE, OR ADVANCED COURSE.

The student must be able to draw a more complicated piece of machinery than in the elementary stage. He must be able to fill in

simple details (bolts, &c.) omitted in the sketches given. He must be able to draw separate enlarged views of details of the piece of machinery of which sketches are given, Lastly, he must be able to answer simple questions as to the materials used in constructing machinery and the reasons of the arrangements adopted.

The examination consists of two parts: (1) Some questions on the qualities of the materials used in construction and on the arrangement, proportions, or strength of the simpler machine details. So far as the questions involve a knowledge of applied mechanics they will be of a simple kind, and will be confined to the application of mechanical principles to specific cases of designing; (2) a rough sketch of some simple machine or portion of a machine will be given in which there are various details of bolts, joints, gearing, framing, &c., and from this a pencil working drawing, drawn to scale, will have to be produced. The remarks as to the character of the drawing in the elementary stage are also applicable to this.

Riveted Joints.—Ordinary proportions of a riveted joint for wrought-iron plates. Pitch of rivets. Conditions fixing the minimum distance of rivets from each other, and from the edge of the plate.

Mode of treating plates where three or more overlap. Forms of boiler stays.

Bolts.—Meaning of term pitch of screw. Forms of Whitworth and other screw threads. Modes of locking nuts. Ordinary proportions of nuts and bolt-heads.

Keys and Cotters.—Arrangements of key and cotter fastenings. Taper of keys and cotters. Proportions of cotter for a given rod. Modes of fixing cotters.

Shafting.—Forms of shaft couplings. Distinction between fast, disengaging, and universal couplings.

Bearings.—Proportions of an ordinary pedestal. Arrangement of footstep bearings. Modes of lubricating bearings.

Toothed Gearing.—Material of gearing. Nature and use of mortise wheels. Ordinary forms of teeth. Meaning of the terms face, flank, clearance. Relation of pitch, number of teeth, and diameter. Velocity ratio of a pair of wheels. Ordinary proportions of teeth.

Belt Gearing.—Velocity ratio of a pair of pulleys. Use of guide pulleys. Joints of belting.

Linkwork.—Ordinary arrangement of cranks, levers, cross-heads, connecting rods, and coupling rods.

Valves.—Lap, lead, and travel of slide valve.

The student will be required to draw to scale, in pencil, from sketches, a piece of machinery, and to make separate drawings in some cases of special details. Examples of the subjects selected to test the candidate's knowledge are given below—

Simple steam cylinder and valve chest, with valve passages..

Cross head and slide block for horizontal engine.

Air pump condenser and valves.

Force pump and valves.

Simple arrangement of gearing, pedestals, and framing.

Lathe headstock, or other portion of a machine tool.

Examination for Honours.

The honours examination is twofold. There is a written examination designed to test the student's knowledge of the principles involved in machine design, and an exercise intended to test his skill in drawing. To pass the written examination, the student must have a knowledge of the materials used in machine construction, their properties, and the modes of shaping them. He should have a general knowledge of the elastic and breaking strength of the most ordinary materials, and of the rules for the resistance of the simpler pieces to straining actions of different kinds. Questions will also be set on the application of kinematical and dynamical principles to such problems as most frequently arise in ordinary machine designing. The actual arrangements adopted in the most common engines, machine tools, transmissive machinery, &c., either for convenience of construction, to ensure durability, or to reduce waste of work, should be known. The following statement includes the most important subjects which should be studied.

Materials commonly used.—Cast iron, wrought iron, steel, copper, gun metal, brass; their composition and the modes of working them, so far as it affects their use in machinery,

Strength of Materials.—The physical constants of elasticity determined by experiment, elastic strength, breaking strength. working strength, moduli of elasticity, resistance of bars and cylinders to tension and compression.

Resistance of bars, axles, &c., to bending. Bending moment, moment of resistance to bending, modulus of section, distribution of bending moment under different modes of loading. Simpler forms of beams of uniform strength.

Resistance to shearing. Bolts, pins, rivets.

Resistance to torsion.

Strength of long columns and of thin cylinders under external pressure.

Compound stress. Rules for combining tension or thrust and bending; and torsion and bending.

Strength of riveted joints. Modification of the resistance of plates and rivets in manufacture. Usual proportions of pitch and diameter of rivets. Strength of boilers. Strength of stayed surfaces. Usual proportions of bolts, keys and cotters. Forms and proportions of pipes, pipe joints, and cylinders subjected to internal pressure.

Proportions of journals as depending on strength and durability. Axles and shafts. Allowance for bending in shafts. Stiffness of shafts. Forms of cranked shafts. Shaft couplings. Bearings for shafts.

Friction and toothed gearing. Velocity ratio of wheels, as depending on diameter and number of teeth. Determination of forms of teeth. Strength of teeth.

Belt gearing. Difference of tension in a belt as depending on friction. Power transmitted. Strength of belt. Ordinary arrangements of belting. Belt pulleys. Forms and proportions of ordinary chains.

Forms and proportions of cranks, eccentrics, connecting rods, and cross-heads. Stresses in crank and crankshaft due to given piston pressures. Computation of balance weights. Wearing surface of slides.

Construction of pistons. Influence of inertia of piston on distribution of crank effort during the stroke.

Principles regulating the construction of valves. Theory of engine slide valves. Zeuner's diagram. Valve ellipse. Ordinary forms of valve gear. The simpler problems of the efficiency of machines as depending on friction. Regulating mechanism. Governors. Determination of weight of fly-wheels.

In addition the candidate will have to design some portion of an engine or machine, from a general description, and to prescribed dimensions. General and detail drawings are required to be made, and these may be inked, and coloured, and dimensioned, like ordinary working drawings. It is recommended that all the drawings should be on sheets of imperial size. With the drawings may be sent a statement of any calculations made in working out the design, and of the reasons for any of the arrangements adopted. In judging the drawings of the candidates, both skill in drawing and knowledge of the construction, and proportions of machinery will be taken into account. The candidate should therefore aim to produce both a workmanlike drawing and a correct and well proportioned design. This exercise the candidate will have to execute at his own home in a specified time.

Subject VI.—THEORETICAL MECHANICS, INCLUDING HYDROSTATICS AND PNEUMATICS.

First Stage, or Elementary Course.

Physical Preliminaries.

In the first stage it is intended that the science of theoretical mechanics should be treated from a purely physical point of view. The attention of the student should therefore be mainly directed to obtaining clear views of the elementary laws of the science, considered simply as matters of fact, which have been ascertained and can be illustrated by experiment. The mathematical development of these laws, and their application to the solution of questions more or less complicated, is reserved for a higher stage of the student's progress. He should therefore be able to make clear and brief statements of the various principles referred to in the following synopsis. He should be able to describe the various machines mentioned, to make sketches of them with pen and ink, and to show that he understands the principles involved in their construction or exemplified by their use. He should further be able to answer questions involving easy applications of the principles which have been the subject of his study. It must be added that the power of making clear brief statements of principles and of illustrating them with distinctly drawn, not highly finished, diagrams is one, the acquisition of which cannot be too strongly

insisted on. With reference to the amount of mathematical knowledge needed by the student for passing in the first stage of the present subject, it may be stated that nothing will be indispensable beyond the first stage of mathematics, and that the examples will be, as far as possible, simply arithmetical, including such as can be answered by means of an easy diagram drawn to scale. For this purpose all students should bring with them to the examination a pair of compasses, a scale of equal parts, and a protractor.

1. Measure of time, space, velocity, whether uniform or variable, acceleration of velocity, the accelerative effect of a constant force, quantity of matter, momentum, force, the absolute unit of force.

2. Elements required for the specification of a force. Composition of forces, especially of two forces, whether their directions intersect or are parallel. A statical couple. Moment of a force. Centre of parallel forces. Work done by a force. Unit of work foot-pound and horse-power.

3. Different states of matter. Divisibility, compressibility, elasticity, resistance to elongation, compression, bending and torsion.

4. Centre of gravity and its position in simple cases. Equilibrium of a body capable of turning on a fixed point or fulcrum. Levers; the steelyard; the balance and its sensibility. Equilibrium of a body resting on a horizontal plane. Stable and unstable equilibrium.

5. Laws of uniformly accelerated motion, and the formulæ embodying them, viz. $v = V + ft$, $s = Vt + \frac{1}{2}ft^2$, $v^2 = V^2 + 2fs$. Atwood's machine, Morin's machine.

6. Uniform motion in a circle; centrifugal force. Small oscillations of a simple pendulum; also of a compound pendulum. Convertibility of the centres of oscillation and suspension. Determination of the numerical value of the force of gravity. Inequality of the force of gravity at different places.

7. Kinetic energy or accumulated work of a moving particle.

8. Law of transmission of pressure through a fluid. Pressure of a fluid against a plane area. The centre of pressure.

9. Pressure of a fluid on a body wholly or partly immersed. Specific gravity of a solid or liquid and its determination in simple cases. The specific gravity balance. Nicholson's hydrometer. Hydrometers of variable immersion. The specific gravity bottle.

10. Conditions of equilibrium of a floating body, and of its stability. The metacentre.

11. The general phenomena of capillary elevation and depression. The law of diameters.

12. Experimental proof that air is a heavy elastic fluid. Torricelli's experiment. The cistern barometer. The aneroid barometer.

13. Boyle's or Mariotte's law. Unequal compressibility of different gases. Limitation of Boyle's law. The compressed air manometer.

14. The ordinary suction pump, the force required to work it, and the limits of its action. The forcing pump. The siphon. The air pump; the measure of the degree of its exhaustion; the mercurial gauge. The hydraulic press.

Second Stage or Advanced Course.

In the advanced course the student will be concerned with the mathematical treatment of the principles comprised in the elementary course, so far, at least, as the subject can be discussed with the aid of elementary mathematics, of so much, for instance, as is comprised in the first and second stages of mathematics. The student should pay particular attention to the proof of the various theorems of mechanics referred to in the following synopsis, and should be able to answer questions in which those theorems are illustrated or applied. For instance, he should not merely know what is meant by "centrifugal force," and the fact that its amount is given by the formula—

$$\frac{m v^2}{r}$$

but he should be able to give the reasoning by which that fact is proved, and to apply his knowledge to a moderately difficult example. He should not merely know that as a matter of fact the centres of suspension and oscillation are reciprocal, but be able to prove that they are so, and to determine in a simple case the position of the centre of oscillation with reference to a given centre of suspension. The examination in the advanced course will therefore pre-suppose a thorough knowledge of the elementary course, and will be directed to ascertaining that the student possesses this knowledge, and also that he has studied the various developments of the subject to be found in text books of the elements of mechanics and hydrostatics. Every student should bring with him to the examination the drawing instruments mentioned in the syllabus of the first stage. The points to which particular attention should be directed are the following:—

1. The composition of two, and of any number of forces—including parallel forces and couples—acting in one plane, and the conditions of their equilibrium. The centre of parallel forces.

2. Determination of the position of the centre of gravity in ordinary cases, and applications of its properties.

3. Reaction of rough surfaces; the limiting angle of resistance or angle of friction; the coefficient of friction; the laws of friction.

4. Equilibrium of simple machines when the friction of the parts is taken into account. Inclined plane, wedge, screw, pulleys, equilibrium of body resting on a rough axle.

5. Principle of virtual velocities and its applications. Questions on the work of agents.

6. Rectilinear motion under the action of constant forces, particularly on smooth or rough inclined planes. Composition of velocities. Motion of projectiles Motion in a circle. Motion of a simple pendulum.

7. Determination of the vis viva or kinetic energy of, or work accumulated in, a moving particle.

8. Moment of inertia. Effective forces. D'Alembert's principle.

Resultant of effective forces, and work accumulated in the case of a body turning round a fixed line. The fly-wheel. The compound pendulum.

9. Impulsive forces. Direct and oblique impact of spheres. Centre of percussion. The ballistic pendulum.

10. Determination of fluid pressure on plane areas, and of the centre of pressure in simple cases. Questions on floating bodies and on specific gravity.

12. Questions on pressure and elasticity of air. Determination of heights by the barometer.

13. Motion of fluids through small orifices. Torricelli's theorem.

Examination for Honours.

Owing to the great extent of the science of theoretical mechanics, it may be of use to the student to have those parts of the subject marked out to which his attention should, in the first place, be directed. It cannot be too strongly urged on him that the study of the higher branches of mechanics cannot be attempted with advantage unless it is preceded by a thorough knowledge of the elements of the science. The candidate for Honours should therefore be prepared to answer readily any question on the advanced course. Supposing this degree of proficiency attained, his attention should next be directed to the subjects named below.

A.—Statics.

1. The general theory of the composition and resolution of forces and of the equilibrium of a rigid body.
2. Virtual velocities.
3. Composition and resolution of stresses, particularly such as are parallel to one plane.
4. The simpler cases of the deflection and rupture of beams.

B.—Dynamics.

1. The properties of the moments and products of inertia.
2. D'Alembert's principle.
3. Motion of a rigid body about a fixed axis.
4. Motion of a rigid body in space of two dimensions.
5. Vis viva, and other general principles of Mechanics.

Subject VII.—APPLIED MECHANICS.

In order to prepare for this examination the student should carefully inform himself as to the details and construction of the various contrivances, machines, and appliances referred to in the list given below; and in doing so, he must seek to understand the manner in which certain natural laws or mechanical principles receive their useful application. The subject matter covers a wide field, and the particular

apparatus or combination under inquiry may oftentimes be the result of a long series of improvements based upon the intelligent observation of facts. The student will probably perceive that in every case there is some guiding principle or law of action which leads up to the construction, and in this way he will be carried from a knowledge of principles to the power of applying them, or, at least, of understanding the mode of their application. The examination in applied mechanics will therefore be directed towards ascertaining, as far as may be practicable, whether the candidate has approached the study in the manner pointed out.

The list for the first stage is necessarily comprehensive, but the questions will be framed in such a manner that a candidate who has obtained a fair knowledge of a portion only of the subjects may hope to pass with some credit. Easy questions involving arithmetical results may arise, and in particular the student should be able to solve simple mechanical problems by graphic construction. The list for the second stage refers also to a wide range of subjects upon which the student should obtain as much information as possible. He will be liable to questions involving only a very limited knowledge of mathematics.

In the honours paper a fair amount of mathematical knowledge may be required.

First Stage, or Elementary Course.

The subjects for examination will be:—

Measurement.—Line and end measure. Rules, callipers, gauges.

True plane surfaces.—Surface plates. Method of surfacing. Applications in machinery.

The principle of work and its application to simple machines.—Levers. Balances. Safety valves. Pulleys. The snatch-block. Sheaves. The inclined plane. Screws, forms of thread, mechanical characteristics of screw threads. Right and left handed screws, single and double threaded screws. The screw and lever in combination. Screw presses. Lifting jacks. Endless screw and worm wheel. Wheel and axle, its applications. Winch or crab. Power gained by wheelwork.

The conversion of motion.—Endless bands, straps, fast and loose pulleys, guide pulleys. Toothed wheels. Rack and pinion. The crank and connecting rod. Cams. Mangle motions. Ratchet wheels, detents.

Special contrivances.—Such as:—The Fusee. The wheel and compound axle. Weston's pulley block. Escapements. Geneva stop. Fast and slow motion in the head stock of a lathe.

Energy.—What it means. The measure of work stored up in a raised weight or in a heavy mass in motion. The fly wheel. Fly presses.

The pressure of water.—Estimation of water pressure on plane surfaces, such as sluice gates. Pressure gauges. The Hydrostatic press. The accumulator, or vessel for obtaining a supply of water under pressure.

Machines for raising water.—Pumps. Lift pumps. Force pumps. The use of an air vessel.

Materials.—Iron; qualities required for different purposes. Testing of iron for strength and ductility. Steel; hardening and tempering. Copper and tin; their alloys. Gunmetal. Brass.

Strength of materials.—Power of resistance of different materials to tensile and compressive strains. Power of resistance to transverse strains. Influence of form or dimensions of section. Influence of length, of position of load, of distribution of load.

Friction.—The laws of friction. Contrivances for lessening the effect of friction.

In answering the questions, students will be required to make hand sketches of the details of the various parts in a clear and intelligible manner. Great importance will be attached to this requirement.

Second Stage, or Advanced Course.

The subjects for examination will include everything mentioned in the first course, but candidates will be expected to possess a more extended and thorough knowledge of the various details, as well as of theoretical principles.

The additional matter will be the following:—

Miscellaneous details.—The forging of iron. Welding. The casting of iron. Moulding. Soldering. Brazing. The expansion and contraction of metals.

Friction.—Examples where friction is useful. Rolling friction, Brakes. Strap-brakes. Friction, and other dynamometers. The efficiency of machines. Friction grips. Holding power of ropes *when coiled.* Friction clutches.

Strength of materials.—Estimation of transverse strain on a rectangular timber beam. Cast and wrought iron girders. Cantilevers. Buckled plates. The deflection of beams.

Strains in framework.—Simple examples of framework, with corresponding diagrams of stress. Travellers, roofs. Lattice girders Trussed beams.

Shearing and twisting strains.—Cotters, rivets, joints of plates, Strength of shafting to resist torsion. Hollow or solid shafting.

Compressive strains.—Pillars. Piers. T and angle iron struts. Tie bars.

The conversion of motion.—Quick return movements. Linkwork and parallel motions. Peaucellier's invention. Trains of wheels for screw cutting, clockwork. Epicyclic trains. Rope-making machinery. Differential motion of three bevel wheels. Universal joints.

Pressure of air.—Fans, blowers. Air pumps. Gauges for measuring the pressure of air. Construction and efficiency of wind-mills. The diving bell.

Hydraulic machines—Water wheels. Forms of buckets. Pendulum Governor for water wheels. Turbines. Centrifugal pumps. Hydraulic

press. The hydraulic jack. Hydraulic cranes, different powers. Force pump for feeding the accumulator. The water ram.

Description of Machines in Common Use.—Such as :—Cranes. Machines for weighing. Counting and numbering machines. Corn mills. Clocks, Dead beat escapement. The lever escapement. The chronometer escapement. The keyless watch. Hand-printing presses.

Principles and Construction of Hand Tools.—Such as :—Chisels. Planes. Gimlets. Augurs. Saws. Drills. Files.

Machine Tools.—Such as: Lathes, ordinary and screw cutting. Planing, shaping, and slotting machines. Reversing motions. Drilling and boring machines. Punching and shearing machines. Feed motions.

The observations already made with reference to hand sketching apply equally here, and details of machines, such as feed motions, reversing motions, &c., might form the subject of questions, the answers to which will be of no value unless the sketches are correctly given.

Honours.

The above syllabus will sufficiently indicate the nature of the subjects that form the basis for the examination in honours. Candidates must be versed in mechanical principles, and will be asked to give theoretical investigations which may bear upon the subject matter under consideration.

Subject XXII.—STEAM.

First Stage, or Elementary Course.

Students in this course will be required to possess some knowledge of the effects of heat on matter, such as changes of temperature, expansion, change of elasticity, vaporisation, liquefaction; they must also know something of the phenomena of the radiation, absorption, conduction, and convection of heat; they will be liable to questions relating to the mechanical equivalent of heat, as well as to the conversion of work into heat and of heat into work; they must also inform themselves on the following subjects, viz., the causes which influence the boiling temperature of water, the boiling points of fresh and salt water, high-pressure steam, measure of steam pressure by atmospheres, the relation between the pressure, density, and temperature of steam, the specific gravity of steam, the latent heat of steam, the quantity of water required to produce condensation, common and superheated steam, the constituents of sea water.

Early Engines.—Newcomen's atmospheric engine, its defects. The discoveries of Watt. Hornblower's engine.

The Single-Acting Condensing Engine.—Details connected with Watt's single-acting pumping engine; the steam cylinder, the steam, equilibrium, and eduction valves, their action; the steam jacket, the clothing of the cylinder; the condenser, the air pump, the foot valve, the delivery valve, the snifting valve, the hot well; the piston rod,

stuffing boxes and glands, the parallel motion; the method of starting the engine, and of regulating its speed, the cataract.

Double-Acting Condensing Engine.—Details of the various parts, the cylinder, how constructed, the ports or openings into the cylinder; the forms of slide valve in common use, the methods of balancing valves, the three-ported valve, the lap on a valve, the lead of a valve, the eccentric; details of the piston, metallic packing rings; the air pump, jet condenser, gauges for the condenser, the barometer gauge, method of estimating pressure by it, errors in this method, and correction of the same; the crank and connecting rod, the strap, gib, and cotter, the beam, the parallel motion, the governor, the fly-wheel; stopping and starting gear. Various types of direct-acting condensing engines.

The Non-Condensing Engine.—Various types of direct-acting engines.

The Expansion of Steam.—Saturated and superheated steam; law of expansion; the object of expanding steam; modes of carrying out expansive working. Expansion valves; double beat valve, crown valve, gridiron valve; wire drawing of steam, the throttle valve.

Stationary Boilers.—The Cornish boiler, the cylindrical boiler with internal flues, the vertical boiler; heating and fire-grate surfaces, the evaporative power of boilers, boiler chimneys; the strength of boilers, the use of stays, the proving of boilers. Boiler appendages; safety valves, reverse or atmospheric valves, communication or stop valves; the glass water gauge, steam pressure gauge, various forms, the heating of feed water, feed pumps. Priming, its causes and remedies.

The Marine Steam Engine.—Various types of paddle-wheel engines; side lever engine, oscillating engine, vertical trunk engine, &c.; various types of screw propeller engine, such as Penn's trunk engine, Maudslay and Field's return connecting-rod engine, &c. Details of parts connected with the working of marine engines; expansion and reversing gear; bilge and feed pumps.

Marine Boilers.—High and low pressure boilers, general forms and construction; tubes and flues; the funnel and its casing; fire-bridge and ashpit, waste steam pipe, water gauge, gauge cocks, pressure gauges, safety valves, reverse valves, stop valves, feed pumps, boiler hand-pumps; feed or donkey engine; Kingston's valves, blow-out cocks, brine-pumps and brine-valves; the methods of ascertaining the degree of saltness of the water in a boiler, amount of saltness permissible; formation of scale; superheating apparatus; surface condensation.

The Locomotive Engine.—The general construction of a locomotive engine and boiler before the invention of Stephenson, the Killingworth engine; description of the "Rocket" engine by R. Stephenson, as the type of the modern locomotive, the tubular boiler, the draught produced by the discharge of waste steam.

The Boiler.—The fire-box, the inner and outer shell, the cylindrical barrel, the tubes, mode of fixing them, fire-box stays, gusset stays; the ashpit, the smoke box, the blast pipe, mechanical action of the blast; the steam chest, the outer dome, the steam pipe, the regulator, safety valves, pressure gauges; whistles, blow-off cocks, feed pumps, Giffard's injector; evaporative power of the boiler, fire-grate and heating surface, combustion of fuel; the tender, water-tank, tank-engines, brake,

feed pipes; coke-burning engines, methods of consuming smoke in coal-burning engines. Ramsbottom's method of filling the tender.

Details.—Inside cylinders, outside cylinders, steamways, ports, slide valve; water cocks, grease cocks, the piston and packing-rings, piston-rod, guides, connecting rod, eccentrics, the reversing or link motion, reversing lever, sector, expansive working; crank axle and driving wheels, power required for traction, adhesion of the driving wheels, counter weights to cranks, wheels and axles, axle-boxes, bearing springs, buffer and draw springs, friction brakes.

In this examination it is essential that the student should acquire the power of making hand sketches of the various parts which he may be called upon to describe. The observations made in the syllabus for applied mechanics hold equally in this subject, and it is further to be noted that the student is liable to be questioned as to the mechanical principles involved in any of the matters herein mentioned.

Second Stage, or Advanced Course.

Students for this course will be examined in the following additional subjects, as well as in those already set forth:—

Condensation.—Surface condensers, circulating pump; tubes, method of fixing them; amount of water required for condensation.

Compound Cylinder Engines.—Arrangement of cylinders, details of valves.

Practical Working of Marine Engines.—Getting up the steam, filling the boilers, laying the fires, attention to various parts of the engine while the steam is getting up, mode of starting, working the engines at moorings. Priming, its causes and remedies. Duties to machinery when under steam, boilers, fires, &c. Injection pipes. Leaks in engines. Bearings of engines. Expansive working. Management of fuel. Damages and repairs to boiler, &c., after accidents. Duties to engine, &c., on arriving in harbour.

The Indicator.—Description of the instrument, the atmospheric line. Method of taking a diagram. The general configuration of diagram to be expected under various circumstances. Examination of the indicator-diagram when the steam is throttled; when expansive gear alone used, and in other cases. To ascertain the horse-power of an engine by means of the indicator. The indicator-diagram in engines of various types.

Propellers.—Paddle wheels, feathering of the floats, disconnection and immersion of wheels. The screw propeller, various forms, length, angle, pitch, and area of screw blade, disconnecting and raising the screw; the position of the screw propeller in the vessel, twin screws, the slip of the screw; the method of receiving the thrust upon the vessel, soft metal and hard wood bearings.

The Permanent Way of a Railroad.—Varieties of rails in common use, timber sleepers, transverse and longitudinal systems; jointing of rails, the fish joint; the tyres of wheels, their form, adhesion of wheels to the rails, tractive force; general description of switches and crossings.

Theoretical Portion.—Work done during the conversion of water into steam; work done in a steam cylinder when the steam is expanded; work done in the air-pump; work developed by a crank; meaning of absolute temperature; isothermal and adiabatic curves; efficiency of heat engines; estimation of loss of fuel by "blowing out"; calculations relating to parallel motions, such as Watt's and Peaucellier's; estimation of the relative positions of the piston and crank in any part of the stroke; diagram showing the relative motions of the slide and piston; dynamometer, its use in finding the horse-power of an engine.

Honours.

The range of subjects will extend over the whole syllabus.

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STAMFORD STREET AND CHARING CROSS.

APPENDIX III.

Syllabus of the City of London College Engineering Department.

City of London College,

WHITE STREET, MOORFIELDS, E.C.,

IN UNION WITH

The Society of Arts, the Government Department of Science and Art, and the City and Guilds of London Technical Institute.

Patron:

HER MOST GRACIOUS MAJESTY THE QUEEN.

President:

HIS GRACE THE LORD ARCHBISHOP OF CANTERBURY.

FORTY-THIRD ANNUAL SESSION, 1890-91.

SYLLABUS OF LECTURES IN

ENGINEERING DEPARTMENT,

PROFESSOR:

MR. HENRY ADAMS,

M. Inst. C.E., M. I. Mech. E., F.S.I., &c.
President of the Society of Engineers.
Science Certificates: First Class Honours, First Place, 1869.
Queen's Medalist in Science, and Certificated in Art.

Assisted by Mr. R. J. HATTON,

M. Inst. M.E., Science Teacher, First Class Honours.

AND

Mr. S. F. HOWLETT,

Science Teacher, City Guilds Medalist and Prizeman.

For particulars of College Prizes, Syllabus of Work in other Classes, Examination Papers, List of Associates, Members and Registered Students, and a variety of useful information see the "College Calendar," post free 9d.

IMPORTANT NOTICE.

Several of the students in the Engineering Department have obtained good appointments through the College, and employers have frequently expressed their satisfaction at the ability of those engaged by them. A Register is kept at the College, in which students wanting employment may enter their names and addresses.

Former students are requested to make known among their younger friends the facilities for study afforded by the City of London College. There are now forty Professors and Lecturers upon the staff, giving instruction in upwards of 50 different subjects of Science, Art, Language and Literature, divided into 130 classes, and the attendances for the session (seven to nine months) average 70,000. The new and handsome Building, erected at a cost of £16,000, contains accommodation of a superior character for 4,000 Students, and is situate within two minutes' walk of MOORGATE STREET STATION AND TRAMWAY TERMINUS, and within five minutes' of the Broad Street and Liverpool Street Stations and of the Bank. The classes are divided into various stages to suit the progress of students; and all the rooms are amply ventilated and lighted. In addition to the usual periodicals and newspapers, the Reading Room is provided with nearly all the Technical papers, and there is also a good Library.

All fees must be paid in advance at the College. The College Calendar, price 6d., required by all students, will be ready on the 1st October.

DAVID SAVAGE,

Secretary.

☞ Students are requested to notify to Mr. Adams, at his office, 60, Queen Victoria Street, E.C., any change of address, in order that they may receive the Annual Syllabus immediately it is issued. Letters requiring a reply should enclose a stamped addressed envelope.

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TIME TABLE OF CLASSES, 1890-91.

				FEES	COMMENCING
TECHNICAL DRAWING AND DRAWING OFFICE PRACTICE—					
*Beginners & Elementary	Wednesday	7–8.30 p.m. ...		12/-†	1st Oct.
BUILDING CONSTRUCTION—					
*Beginners	Monday	5.30—6.30 p.m.		12/-†	6th Oct.
*Elementary	do.	6.30—7.30	,,	15/-†	,,
*Advanced	do.	7.30—8.30	,,	18/-†	,,
Honours...	do.	8.30—9.30	,,	21/-†	,,
MACHINE CONSTRUCTION—					
*Beginners, Elementary and Advanced	Friday	7.0—8.0 p.m		12/-†	3rd Oct.
Honours	By arrangement.				
CIVIL ENGINEERING— ...	Thursday	7—8	,,	25/-†	2nd Oct.
MECHANICAL ENGINEERING—					
Ordinary Grade... ...	Friday	8—9	,,	21/-†	3rd Oct.
Honours...	By arrangement.				
QUANTITY SURVEYING—					
(Fletcher) Mich. Term...	Friday	6—7	,,	15/-‡	3rd Oct.
(Leaning) Lent Term ...	do.	do.		21/-‡	2nd Jan.
LAND SURVEYING—					
(General) Mich. Term...	Thursday	6—7	,,	§	2nd Oct.
(Surv. Inst.) Lent Term	do.	6—7	,,	§	1st Jan.
(General) Easter Term...	do.	6—7	,,	§	Mar.
Field Work	Saturday Afternoons.				

* Drawing boards and tee squares provided free for use in these classes.

† These fees are for the whole Session, October to May inclusive.

‡ Per course of ten Lectures.

§ See Syllabus, pages 21 to 31.

The fees include free admission to the Reading Room, Coffee Room, Concerts, Lectures, Entertainments, &c. Library (optional) 1s. 6d. per Term extra. A reduction of 1s. per Term is made on joining each class after the first.

Private lessons are given when desired in any subject of this Syllabus, and pupils received in office for general study.

Fees according to subject and time.

SYLLABUS.

Technical Drawing and Construction.

In connection with the Government Department of Science and Art.

" *The valuable text-books on constructional subjects written by Mr. dams afford evidence that the instruction given in these classes is ·actical and thorough.*"—BUILDING NEWS.

The class in Technical Drawing was instituted in 1874, for the purpose of aining students in the principles and practice of Drawing applied to the Arts Construction, to prepare them for entry into Engineers' and Architects' ffices, or to perfect them in their duties if already engaged in such an office. udents under sixteen are recommended to take this subject alone for one ssion, and then to take it in conjunction with one of the Construction asses; neat draughtsmanship being the first essential to a proper study of onstruction.

Students who are regular in their attendance will, under certain conditions, ve the privilege of attending some of the meetings of the various professional cieties. Application should be made to the Professor for cards of mission.

The following subjects, with a few exceptions, are represented by an iborate collection of over 1,000 diagrams drawn by hand to a large scale, loured, and fully dimensioned, in order that the students may prepare from em *working* or *finished* drawings. A new set of these diagrams is in course of eparation, a separate sheet, 24 feet super, being given to each detail. Other bjects are discussed in the class lectures and illustrated by hand sketches on e black board and also by models, and photographs. As far as possible a ogressive and connected course of instruction is given, typical details being lected for fuller demonstration.

TECHNICAL DRAWING.—Instruments required—How to select them—How to cut the pencil points—Method of holding tee square—Mixing Indian ink—Practice in use of instruments—Laying on flat washes of colour—Primary and secondary colours—Practice in figuring and lettering—Practice in joining curves and lines—Meaning of the phrase "drawing to scale"—Scales of various proportions—Irregular figures and block plans for practice in drawing to scale—Copying plans by proportional squares—Scale for enlarging and reducing copies of drawings—Defects in instruments and how to remedy them—Drawing parallel lines by set squares only—Principles of shading—Shading by back lines—Rules for back lines—Shading by flat tints—Shading rivets and bolts—Simplest method of shading cylindrical surfaces—Shading by uniform and graduated lines—Complete shading of curved surfaces—Projection of shadows on flat surfaces—Table of colours to indicate various materials—Colouring for brickwork and concrete—Colouring for earthwork sections—Colouring for slate and tile roofing—Sectional shading in ink or pencil to represent various materials—Tinting and graining for fir and oak—Elevation of door head in ornamental brickwork—Tile paving—Classic mouldings—Projection in vertical, horizontal, and profile planes—Projection of spiral line or helix—Screw thread—Vee and square thread screws—French curves—Construction of ellipse and parabola—Elliptical skylight—Elliptical brick arch over gateway—Elliptical stone arch—Angular projection—Projection of pulley at an angle—Isometrical projection—Construction of isometrical scales—Outlines of arches; semicircular, segment, equilateral, lancet, tudor, and ogee—Window tracery—Geometrical constructions—Conversion of French measures into English—Fluted pilaster and column—Entasis of columns—True elevation of skew arch—Proportional scale for enlarging and reducing—Practical perspective as used by architects—Artistic designs—Competition drawings—Drawing-office practice.

BUILDING CONSTRUCTION.—Joints in woodwork; halving, tenoning, morticing, dovetailing, mitreing, notching, cogging, fishing, scarfing, and tablin—Joints in flooring—Sections of ogee and other mouldings—Architraves—Ledged and braced doors—Varieties of framing, square framed, bead and butt, bead flush, moulded, and bolection moulded—Framed doors—Single, double and framed flooring—Wall plates and pole-plates—Various forms of roofs—Collar beam roof—King, queen, and mansard roof trusses—Scantling of roof timbers—Angle-tie and dragon piece—Quarter partition—Bricknogged partition—Trussed partition—Lath and plaster—Framed partition—Bressumers and flitch girders—Handrailing—Dog-legged and open newel staircase—Details of sashes and window frames—Wood fencing—Portable gangways—Railway platforms—Railway platforms and jetties—Timber trenches and excavations—Timber retaining walls—Sheet planking in coffer dams—Timber piles and pile shoes—Timber bridges—Shoring and strutting—Strength of materials—Holding power of nails and screws—Shrinkage of timber in seasoning—Adhesion of glue—Varieties and properties of timber, &c.

Process of building brick walls—Advantages of bonding—Bond in brick work, various thicknesses—Bonding returns and party walls — Bonding angles, buttresses, &c.—Grouting—Brick paving, flat and on edge—Plain, rough, and gauged arches—Brick piers—Sleeper walls — Brick fender — Door and window jambs — Wood bricks, plugs, and pallets—Footings and foundations—Damp-proof-course—Concrete—Inverted arch—Discharging arch—Pocket for girder—Boundary walls—Dog's tooth moulding—Brick cornices—Raking courses—Barge and sailing courses—Corbelling-out and gathering in—Brick chimney with moulded cap—Varieties of bricks—Hollow brick walls—Section of dock—Brick and stone retaining walls—Oval brick sewer—Concrete walls and arches—Patent flooring and arches for fire-proof construction.

Ashlar facing—Ashlar quoin—Granite base for column—Rubble walling; uncoursed, random coursed, and coursed—Stone steps and landings—Curtail step—Spandrel steps—Cramps, joggles, and dowels—Stone copings; parallel, tilted, feather-edged, and saddle-backed—Stone corbels and templates—Window sills and string courses—Weathering and throating—Chamfering and splaying—Chimney-piece—Balconies—Cornices—Pediments and caps—Balustrades—Ransome's patent stone—Masons' putty—Precautions in bedding and fixing stonework—Chief characteristics of the various periods of British architecture—Ancient orders of architecture—Measurement of Classic architecture.

Laying lead flats—Drip in gutter and lead rolls—Step flashing—Syphon trap in lead pipe—Bell trap—P-trap—Draining and sanitary arrangements—Water service—Slating for roofs—Zinc roofing—Painting—Materials used—Knot stop and prime—Oil colours—Distempering — Whitewashing and limewhiting — Glazing — Crown, sheet, and plate glass.

Bolts, nuts, and washers—Tie bolts and straps—Gibs and cotters—Coach screws—Spikes, nails, and screws—Lewis bolts—Wrought and cast-iron sash frames—Air-bricks and gratings—Rolled iron joist—Riveted joints—Wrought-iron plate and box girders—Cast-iron girders and springers—Cantilevers—Cast-iron stanchions and columns—Wrought-iron roof trusses—Wrought-iron hand-railing—Butterfly railing—Hawksley's, Lindsay's, and Hedges' patent treads — Spiral staircases — Fire-proof vaulting — Corrugated iron roofing—Hand lifts—Hydraulic lifts—Screw piles—Lattice girders

Calculation of strains and strength of materials—Chief provisions of the Metropolitan Building Act—Setting out works—Inspecting and testing.

MACHINE CONSTRUCTION.—Transmission of power by shafting—Key and keyway—Journal—Belt pulley—Rolling and wrapping contact—Bushed bearing—Brass step—Box coupling for shaft—Half-lap and dovetail couplings—Footstep for vertical shaft—Open and crossed belts—Plummer block and brasses—Fly wheel—Crank pin—Wrought and cast iron cranks—Cranked shaft—Slotted link—Motion pin—Split pin and washer—Single and double eye—Forked end of small connecting rod—Bolts and nuts—Whitworth standard proportions—Spanner for tightening nuts—Box and claw spanners—Lock nuts—Various forms of nuts—Varieties of bolts—Gib and cotter connection—Ratchet wheel and pawl—Rack and pinion—Spur wheel and pinion—Riveting—Single and double riveted joints—Rivet heads, various forms—Lap and butt joints—Three-way and four-way cocks—Bib cock—Mitre valve—Stuffing box and gland—Watt's parallel motion—Safety valve—Ramsbottom piston rings—Guide bars and cross-head—Bucket for lift pump—Piston and ram for double-acting force pump—Wrought-iron pump rods with coupling box and cotters—Wrought-iron solid flange coupling for screw shaft—Eccentric sheave and strap—Stuffing box with metallic packing—Slide valve and cylinder face—Sun and planet wheels—Suction, lift, and force pumps—Butterfly valve—Mushroom valve—Flap valves—Clacks—Stop valves—Throttle valve—Eccentric cam—Principle of cam punching press Angle iron and plate shears—Cams for producing uniform velocity—Heartwheel cam—Snail and lobe cams—Eccentric cam with velocity curves—Crocodile shears—Lathe driver and carrier—Face plate for lathe—Quadrant bracket for screw-cutting lathe—Crank centre for foot lathe—Dog chuck—Lathe bed—Speed pulley—Split drum—Flat-linked chain—Short linked crane chain—Stud chains—Chain shackle—Oval counter-weight for crane chain—Conveyance sheave for chain—Chain hook—Ram-horn hook—Stopping, starting, and reversing gear for shafting—Reversing gear for planing machines—Classification of cutting tools—Howlett's adjustable friction gearing—Robertson's friction gearing—Proportions of teeth for spur gearing—Manchester pitch—Cycloidal and epicycloidal teeth—Involute teeth—Willis' odontograph—Mitre wheels—Bevel gearing—Reversing gears—Quick return motions—Worm-wheel and screw—Screw-cutting—To find change wheels for single and double trains—Skew gearing—Skew belt—Reversing gear by belts—Pillow block in wall—Hanging bracket for shafting—Various forms of keys, and methods of keying—Varieties of screw threads—Whitworth standard vee thread—American standard thread—Riveted joints, three and four plates over-lapping—Proportions of rivets in steam and watertight joints—Steam engine governor—Syphon, piston, and needle lubricators—Wilson's impermeator—Regulating valve and standard—Cowburn's dead-weight safety valve—Twin safety valve for boilers—Ramsbottom's safety valve—Gauge-cocks for boiler—Gauge-glass and fittings—Manhole and door—Boiler furnace—Parallel motions for land and marine engines—Link motions—Clutch coupling—Fowler's clip drum - Snatch head—Snatch block—Block tackle—Screw jack—Hydraulic jack—Screw propeller—Spiral and volute springs—Wrought and cast-iron girders and columns—Units employed in engineering calculations—Principles of leverage—Virtual velocities—Construction of velocity curves—Friction—Strains,

tension, compression, torsion, shearing, bending, elasticity—Co-efficient of effect or modulus—Factor of safety—Indicator diagrams—Case-hardening —Chilled and malleable cast-iron—Pattern making and moulding—Chief characteristics of various forms of Steam Engine and Boiler, &c., &c.

The foregoing Classes are all in connection with the Science and Art Department, and are placed at a low fee to enable artizans to avail themselves of the privileges afforded by the College. The numerous valuable Scholarships and Prizes detailed on the next page enable an industrious Student to obtain a free education of an advanced character and a large sum for the purchase of books, apparatus, &c.

In these classes the students are expected to make, within the hour, a complete pencil drawing to scale from a large diagram, the subject being so graduated in difficulty as to render this quite possible to all who attend regularly and keep up their practice. The drawings have then to be inked in and coloured at home or in the Class for Drawing Office Practice, the "finish" depending upon the time and ability at command. After examination by the Professor, the drawings requiring correction are returned to the students; they are then collected, and at the close of the session sent to South Kensington for examination by the Art Department, when prizes are awarded to all who show good progress. The drawings are finally returned to the students on the first class night of the ensuing Session.

The Students have been particularly successful at the various Examinations owing to the all-round excellence inculcated. Many employers ignore the Certificates of the Science and Art Department from the defective result produced in students by the system of "cram" adopted in many of the unattached Science classes. By the system adopted at the City of London College the Students are sufficiently prepared for the various examinations while they are rendered really efficient Assistants to Engineers, Architects and others. The successes at South Kensington Science Examinations alone including the Honours Stage, have averaged over 90 per cent. since the formation of the classes in 1869, while many students have obtained appointments (by examination) in various Public Departments.

TEXT-BOOKS.—TECHNICAL DRAWING AND ALL CLASSES: Adams', "Class Notes" with Note-book and pencil, 6d.

Building Construction :—Burrell's "Building Construction" (Longmans 2s. 6d.) for Beginners and Elementary Students; "Notes on Building Construction" (Rivingtons), vol. I. 10s. 6d., vol. II. 10s. 6d., vol. III., £1 1s., for Advanced Students; Adams' "Designing Wrought and Cast Iron Structures," 1s. 6d. per part; Seddon's "Builder's Work," 6s.; Adams' "Strains in Ironwork," 5s., and Wray's "Theory of Construction," 10s. 6d., for Honours students.

Machine Construction :—"Low's Machine Design" (Longmans), 2s., for Beginners; "Unwin's Machine Design" (Longmans), 6s., for Elementary Students; Kennedy's "Mechanics of Machinery" (Macmillan), 12s. 6d., for Advanced Students.

In each case the more advanced classes should be acquainted with all the books recommended to the preceding classes.

Adams' "Notes in Mechanical Engineering," 2s. 6d., will be found a useful addition to the text-books named above.

Instruments and drawing materials can be obtained in the Classes, and accommodation is provided for drawing-boards and T-squares to be left during the week.

PRIZES, &c.

The Students in these Classes are eligible for the following Prizes. For conditions of competition see College Calendar :—

The "LUBBOCK" SCHOLARSHIP of £10 awarded on the result of the annual examinations, of which these subjects form a part.

The "MITCHELL" APPLIED SCIENCE STUDENTSHIP, value £10, do., do.

The "MITCHELL" ART STUDENTSHIP, value £10, do. do.

The "SADDLERS' COMPANY" APPLIED PHYSICS STUDENTSHIPS (2) value £10 10s. each.

The ASSOCIATESHIP of the CITY of LONDON COLLEGE, conferred after three years' successful study, upon application to the Council.

COLLEGE PRIZES of £1 in each subject and **CERTIFICATES** of three grades.

The "**ADAMS**" **PRIZES** of £2 2s. and £1 1s. in Architectural Designing; £1 1s. in Machine Construction taken with Mechanical Engineering; two of £1 1s. in Building Construction, and two of £1 1s. in Machine Construction. One of the prizes in each of the last two subjects is limited to first year students.

The "**MEDHURST**" **PRIZE** of £3 in Books.

QUEEN'S MEDALS to those who obtain places at the Honours Examinations.

QUEEN'S PRIZES to those obtaining First-Class certificates in the advanced stage at the May Examinations, who have previously passed in the elementary stage.

NATIONAL COMPETITION MEDALS for special excellence in Mechanical and Architectural Drawing.

ART PRIZES of second and third grade for meritorious sets of Drawings, and also for single works of special merit.

Twenty-five **WHITWORTH SCHOLARSHIPS** of £100 to £200 per annum, and twelve **NATIONAL SCHOLARSHIPS** to the most successful students in the May Examinations.

ROYAL ALBERT SCHOLARSHIPS of £50 per annum for three years, and free instruction at the Royal School of Mines.

INDUSTRIAL FREE STUDENTSHIPS for study at South Kensington Museum, Library, and Schools, for periods of from two to nine months. Detailed rules on application to the Department of Science and Art.

FREE ADMISSIONS to the Educational Libraries and Museums at South Kensington and Bethnal Green, to all Students who pass in the Advanced Stage of either subject.

Since 1874 *the students, under* Mr. ADAMS, *have taken at the* MAY SCIENCE EXAMINATIONS :—2 *Whitworth Scholarships*, £100 *per annum*; 1 *Queen's Silver Medal*, 1 *Bronze Medal*, 37 *places in Honours*, 175 *Queen's Prizes*, 307 *First-Class Certificates, and* 393 *Second-Class Certificates. They have also obtained in the Examination of Drawings*:— *National Competition*, 1 *Bronze Medal*; 38 *Third Grade Prizes*, 122 *Second Grade Prizes, and, up to* 1886, 214 *Awards of Marks equivalent to Honorable Mention. They have gained, in addition, a large number of College and Special Prizes and Certificates.*

Building Construction Honours.

A separate class is now formed for those students who intend sitting for honours at the May Examination. They should hold at least a Second Class Advanced Certificate, and will have to pass in the First Class of the advanced stage before competing in honours. Other students are allowed to attend this course, and it will be found useful in preparation for the Architectural Association, which they are recommended to join, for the Examinations in the Architectural Departments of the Admiralty, Office of Works, War Department, and the Royal Institute of British Architects.

Architectural Competition.

Subject for 1890-91:-

A LYCH GATE.

Particulars:—The material and treatment are left entirely to the competitor, but more credit will be given for a simple design carefully worked than an elaborate and incomplete design.

Drawings:—Front and side elevations, longitudinal and transverse sections, plan of foundations and roof, ground plan, and perspective view in pen and ink or colour. Sheets not to exceed 30 in. by 22 in. Scale ¼ in. to 1 foot.

Time:—The whole of the Drawings must be delivered to the Professor not later than 1st April.

Conditions of Competition:—See College Calendar.

Reading Room.

The following papers, among others, are now kept in the Reading Room of the College for the use of all students, viz :—

Engineering.	Builder.
Engineer.	Building News
English Mechanic.	Architect.
Practical Engineer.	Illust. Carp. & Builder.
Mechanical World.	Estates Gazette.
Mechanical Progress.	Science and Art.

Technical Library and Museum.

A valuable collection of technical works has been added to the Library, and is now available for circulation or reference. A technical museum is in course of formation, and gifts of illustrative objects in all branches are solicited.

Science Society.

The ordinary meetings are held on the first Tuesday in each month at 8 p.m., Subscription 2s. 6d. per annum. Papers on scientific subjects are read and discussed at the ordinary meetings, and excursions are made to Works and places of interest through the summer.

The journal of the Society is on sale in the library. and will be forwarded free by post to subscribers of an additional 2s. 6d. per annum. It is published on the 1st of each month, and contains useful notes in addition to the papers read before the Members.

Civil Engineering.

(For Building Construction Honours, see page 12).

This class is now detached from the Building Construction, Honours Division, and will be entirely devoted to the principles and practice of Civil Engineering. There is, however, much that is common to both branches, and many students may find it desirable to attend both classes.

The home work is an important feature of the system adopted at the College, helping to fix upon the memory the methods of procedure in designing and the principles upon which it depends. Students are expected to bring some home work each week in answer to the questions which are set upon the subject of the lectures.

This course will be found useful in preparation for the examinations of the Engineering Departments of the Admiralty, Office of Works, War Deparment, &c., the Association of Municipal and Sanitary Engineers, and others.

Among the subjects to be dealt with are:—

Foundations– Shoring and Underpinning—Coffer-dams and Piling—Embankments and Retaining Walls—Watercourses, Culverts and Sewers—Bridges—Piers and Jetties—Chimney Shafts—Roofs, &c.

TEXT BOOKS:—Rankine's Applied Mechanics; Law's Civil Engineering (Weale's Series); Wray's Theory of Construction 10s. 6d.; Adams' Strains in Ironwork 5s,; Adams' Strength of Iron and Steel 6d.; Adams' Designing Wrot. and Cast Iron Structures, Parts I. to V., 1s. 6d. each.

SPECIAL PRIZE, The "Victoria Jubilee Prize of the Saddlers' Company", value ten guineas will be awarded to the student who shall take the highest position at the College Annual Examination in Civil Engineering and Land Surveying including Engineering Field Work. For further particulars, see College Calendar.

Mechanical Engineering.

In connection with the City and Guilds of London Institute.

Prof. Silvanus P. Thompson, Principal of the City and Guilds Technical College, Finsbury, says:—

"The City of London College . . . is not only doing admirable work in its literary and scientific classes, but has a capital engineering class."

* * The class in which Mechanical Engineering is taught by Mr. Henry Adams is highly popular.—*Daily News.*

THIS Class will be found particularly useful to Honours Students in Machine Construction, and to those competing for Whitworth Scholarships or Exhibitions of the Science and Art Department.

The Course of instruction and the Examination, as decided by the Committee, will be founded upon such subjects as the following, but will not necessarily be confined to these subjects :—

1. Practical shopwork and processes. Operations of tempering, welding, riveting, etc. Pattern making, moulding and foundry work. The use of the ordinary machines of an engineer's shop. Fitting-shop work including scraping and the use of gauges. Marking off. Erecting.

2. The steam engine and boiler, stationary, marine and locomotive; general questions as to design, arrangement, management and working. The construction and use of the most common engine and boiler fittings, including the steam engine indicator.

3. Pumps and pumping engines, including the Cornish engines. Pump valves. Centrifugal pumps and turbines. Water-pressure engines and hydraulic machinery in general.

4. The design and proportion of the simpler machine details, including the making of freehand dimensioned sketches, roughly to scale. Mechanisms—means of obtaining and transmitting special motions in machinery. Spur and other forms of toothed gearing.

*5. The strength and other properties of the principal materials used in engineering :—cast and wrought iron and steel, gun metal, brass, etc. Elementary consideration of the strength of ties, struts, shafts and beams, and the methods of coupling or joining most suitable for each case. Ordinary shop test for the strength and quality of materials.

* The next course of Lectures will commence at this point.

The Technological Examinations will be held at the College, and care will be taken that the Ordinary or "Pass" Stage shall be of such a nature as to be passed by an intelligent workman at any mechanical engineering trade, who

having attended the course of lectures, and with some knowledge of the science subjects mentioned below, has inquired and read books about his trade. All candidates will be expected to know something of sections 1, 2 and 3, and a special knowledge of 2 or 3, or of 4 and 5, or of 6 will be sufficient for passing the examination.

Those applying for the FULL TECHNOLOGICAL CERTIFICATE will be required to have passed the Science and Art Department's Examination (at least in the Elementary Stage) in two of the following Science subjects, viz.:—No. I.—Practical Plane and Solid Geometry; II.—Machine Construction and Drawing; V.—Mathematics; VI.—Theoretical Mechanics; VII.—Applied Mechanics; X.—Inorganic Chemistry; XIX.—Metallurgy; XXII.—Steam; all of which are taught in the College.

A Second Grade Certificate in Freehand and Model Drawing together with one Science Certificate will be accepted in lieu of the two Science Certificates named above.

Certificates (First and Second Class) will be awarded to successful candidates in each grade. Prizes, as follow, will be given in this subject, provided the merits of the candidates justify the Examiners in awarding them:—

Honours Grade	1st Prize, £5 and Silver Medal. 2nd Prize, £5 and Bronze Medal.
Pass or Ordinary Grade	1st Prize, £3 and Silver Medal. 2nd Prize, £3 and Bronze Medal. 3rd Prize, £2 and Bronze Medal. 4th Prize, £1 and Bronze Medal. 5th Prize, a Bronze Medal.

An additional Prize of £1 1s. will be given by the Professor, for particulars see College Calendar.

TEXT-BOOK REQUIRED:—Adams' "Notes in Mechanical Engineering," 2s. 6d.

BOOKS RECOMMENDED FOR REFERENCE:—Shelley's "Workshop Appliances," Box's "Strength of Materials," Unwin's "Machine Design," Smith's "Cutting Tools," Fairbairn's "Mills and Mill Work," Magnus's "Hydrostatics," Wormell's "Thermodynamics," Perry's "Steam" Rankine's "Steam Engine," Wilson's "Steam Boilers," Spretson's "Casting and Founding," Knight's "Mechanician," Molesworth's "Pocket Book," Seaton's "Manual of Marine Engineering," Rigg's "Steam Engine," Barber's "Engineers' Sketch Book."

These books may be consulted at the Patent Office Library, which is open free till 10 p.m. every evening.

NOTE:—One of the Students attending these lectures passed in Honours, Machine Construction, and obtained a Whitworth Scholarship of £100 per annum, at the examination in 1883. Another, who was a working fitter when he joined the College 5 years previously, has obtained an appointment abroad at £700 per annum, with a house, &c. Another has passed the Extra First Class Engineers' Examination of the Marine Department of the Board of Trade, and is now an Engineer-Surveyor to Lloyds' Register. At the 1888 City Guilds' Examination four obtained First Class Honours and one Second Class.

COURSE OF EIGHT ELEMENTARY LECTURES

ON

"Strains in Ironwork."

LECTURE I.—Introduction—Varieties and properties of iron—Definitions of load, stress, and strain—Various modes of strain—Popular use of term strain—Breaking weight—Safe load—Factor of safety—Strength of wrought-iron, steel, and cast-iron—Sectional area—Substitution of letters for words and figures—Formulæ—Leverage—Division into three orders—Principle of each identical—Power, weight and fulcrum, terms only nominal—Power or active force, weight or passive force—Leverage simply a question of proportion—Conversion into formulæ—Examples.

LECTURE II.—Pressure of loaded beams on the supports—Girders and roofs found in same way—Load in centre and out of centre—Parallelogram of forces—Definition and explanation—Composition and resolution of forces—Use in finding effect of load on inclined struts—Horizontal thrust—Combination of parallelograms—Graphic delineation of strains—Leverage by diagrams—Case of similar triangles—Application of pressure of loaded girder on supports—Polygon of forces—Reciprocal diagram—Strain in a strut varies with the angle—Inclined struts—Value of trigonometry—Calculations may be made without it—Horizontal strut—Examples.

LECTURE III.—Distributed load carried on horizontal beam—When inclined, strain varies with angle of bearing surface on support—Lean-to roof—Strain in pair of inclined rafters—Span roof—Tie rod—King bolt—Trussed beam—Strains in same—Strength of girder according to method of fixing and position of load—Cantilevers—Ordinary girders—Continuous girders—Typical form of cross-section of girder—action of load on a cantilever—Distribution of the strains—Investigation of leverage—Construction of formulæ—Diagram of strains; tension, compression and shearing—Strain at intermediate points found by ordinates—Examples.

LECTURE IV.—Effect of distributed load—Strain varies as the ordinates to a parabola—Setting out parabola—Method when particular points only are required—General calculation of strains in a girder divided into three stages, pressure on supports, strain in flanges, strain in web—Girder with concentrated load in any position—Maximum strain immediately under load—Variation of strain between extremities—Investigation by diagrams and formulæ—Also by leverage—Combination of diagrams from two or more loads—Special diagrams for rapid use—Girder with distributed load, method of finding strains—Proportioning material to resist the strains—Examples.

LECTURE V.—Girder with distributed load, other forms of diagram—Construction of ordinary formulæ—Girders with intermediate supports—Continuous girders—Proportion of spans—Action of loads—Points of contrary flexure—Diagram of strains—Formulæ—Humber's Handy Book, recommended for general reference—Moving loads—Moving loads on cast-iron girders—Factor of safety—Formula for cast-iron bridge girders—Strength of beams L and T irons—Transverse strains or rafters—Struts, stanchions, and columns—Joints and fastenings—Rivets, pins and bolts—Single or double shear—Examples.

LECTURE VI.—Open web girders—Warren, lattice and trellis girders—Angle of inclination of bars—Proportion of depth to length—Warren girder under central concentrated load—Application of parallelogram of forces—All bars equally strained—Strain in flanges cumulative towards the centre of span—Value of strain at each part in terms of x.—Vertical ends to girders, how affected by position of last bar—Warren girder under distributed load—Apportioning the load on each span—Action of load from point of application to each support—Bars not equally strained—Strains worked out by parallelogram of force, commencing at support—Strains on cranes—Ordinary mode of working incorrect—Application of load is diagonally through sheave pin—Angle of jib affects strains—Examples.

LECTURE VII.—The reciprocal diagram of forces—Explanation of the principle—General knowledge of strains necessary before use can be made of this system—Construction of diagram—Lettering spaces instead of lines—General directions for constructing diagrams—Application to roofs—Diagrams for single and double rafters—For span roof with tie rod—For same with addition of king bolt—For ordinary king post roof truss—For roof with king and queen rods—For span roof with tie rod and double king bolt—For same with addition of struts—For same having additional ties and struts for larger span—For span roof with king bolt and cambered tie rod—For same with open king bolts—For trussed rafter roof—Examples.

LECTURE VIII.—Application of reciprocal diagram to lattice girders—Diagram for Warren girder, with central load supported on top flange—For same with load on bottom flange—For same with additional bays—For same with distributed load on top flange—For same with load on bottom flange—For lattice girder, with bars intersecting at 45° under concentrated and distributed loads—For lattice girder with vertical bars—Examples.

The above course is now published with full illustrations, *see page* 38.

Quantity Surveying.

ELEMENTARY COURSE.—MICHAELMAS TERM.

In this course of ten Lectures sufficient information is given to enable any intelligent student to take off quantities, and bill them in accordance with the ordinary practice for small jobs and builders' purposes. The modes of measuring in each trade, with the deductions, allowances and extras, will be fully explained.

TEXT-BOOK REQUIRED. — Banister Fletcher's "Quantities," 6s. (Batsford).

ADVANCED COURSE.—LENT TERM

IN PREPARATION FOR THE

SURVEYORS' INSTITUTION EXAMINATIONS.

This is a Special Course of Ten Lectures, given with a view to prepare Students for the Examination in quantities of the Surveyors' Institution. It will deal with Quantities in accordance with the best London practice of professional Quantity Surveyors.

The work will be more advanced than in the previous course, so that Students may with propriety attend both; they should have a practical knowledge of Building Construction equal to, at least, a first class in the Elementary Stage of the Science Examination. Questions and sketches for home work are supplied to practise students in taking off and billing quantities in proper form. The answers to be given upon properly ruled paper, and each item to be priced out at current rates.

Demonstrations of practical measuring will also be givin.

TEXT-BOOK REQUIRED :— Leaning's "Quantity Surveying" (Spon), 9s.

RECOMMENDED FOR REFERENCE :—"Notes in Building Construction," Vol. I., 10s. 6d.; Vol. II., 10s. 6d.; Vol. III., £1 1s.; Laxton's "Price Book," 4s. 6d.; Banister Fletcher's "Metropolitan Building Acts," 6s. 6d.; "Estimating" (Batsford) 6s. 6d; Seddon's "Builders' Work," 16s. Leaning's "Set of Contract Documents" (Spon), 10s. 6d.

A Prize of £1 1s. will be given by the Council of the College to the student who, having regularly attended the lectures of the current session, passes the best examination. Certificates of three grades will also be awarded.

Surveyors' Institution.

EXAMINATION RESULTS

Obtained by Students of the City of London College.

In the 1884 Examination, £15 15s. Prize and 4 places. In 1885 the £15 "Institution" Prize and £15 "Driver" Prize, and 9 places, including the first in each sub-division. In 1886 the £15 "Institution" Prize, and 10 places. In 1887 the £10 10s. Prize and 12 places. In 1888 the £15 15s. Prize and 17 places, including half the successful candidates in the Building sub-division, and one-third of those in the Valuation sub-division. In 1889, the Special Prize and 14 places, including 4 out of the 9 Fellowships. In 1890 the £15 "Institution" Prize and 21 places, including 6 Fellowships.

SPECIAL COURSE OF LECTURES AND FIELD-WORK

IN

Land Surveying and Levelling,

IN PREPARATION FOR THE

SURVEYORS' INSTITUTION EXAMINATIONS.

We are glad to see that the class of this able lecturer is so well attended, as we are in a position to speak of the soundness and clearness of his instruction.—LAND AGENTS' RECORD.

In this course the work is summarised, so that the whole ground may be covered in about ten weeks, from January to March. It is more especially addressed to the requirements of the Syllabus of Examinations of the Surveyors' Institution, and is adapted to those students who have already some knowledge of the subject. Others are recommended to take the General Course detailed in the next Syllabus, and sit for examination the following year.

Theodolites, Levels, and other instruments are lent to students for private practice at a moderate charge.

Lecture 1.—Principles of Land Surveying—Application of practical geometry and mensuration—Standards of measurement—Measuring instruments—Calculating areas—Tabulating the working—Plotting and use of scales—Base lines—Magnetic bearing and true north—Tie and check lines—Gunter's chain and arrows—Station poles—Field books—Offsets and offset staff—Area of offset pieces—Examples for entry in field book and plotting.

Lecture 2.—Mode of surveying for area only—Inset pieces—Give and take line—Optical square and cross staff, construction and use—Line ranger—Nature of boundaries, how shown on plan—Obtaining area by equalising lines, dividing plot up into triangles—Examples for plotting and calculation.

Lecture 3.—Typical outlines of chain surveys for open land, woods, lakes, &c.—Representation of trees upon plans—Obstructions to continuations of chain line—Measurement of gap—Areas by computing scale—By Planimeter—Field notes of chain lines (without offsets) from several surveys.

Lecture 4.—Various systems of projecting plans and maps—Ordnance survey—Surveying over hilly ground—Correction for inclination, how made—Indication of hilly ground on plans—Hachures and contour lines—Clinometer—Setting out drainage of new estate—Preparation of plans for Tithe Commission—Field notes of survey of small estate.

Lecture 5.—Traversing with the chain—With Prismatic compass—Plotting a compass traverse—Reduction to a single meridian—Closing a traverse—Checking by internal angles—Field notes of traverse surveys.

Lecture 6.—Definition of levelling—Datum line, level line, horizontal line—Description of Gravatt's Dumpy level, Builder's Dumpy, Y level—Temporary and permanent adjustments—Level staff—Curvature and refraction—Simple and compound levelling—Questions for home work.

Field Lesson 1.—Chain surveying—Throwing chain—Setting station poles, ranging lines—Taking bearing with compass—Chaining lines—Use of offset staff—Box tape—Cross staff—Optical square—Line ranger—Whites.

Lecture 7.—Bench marks—Ordnance datum—Trinity datum—Ordnance survey maps—Level book—Field columns and plotting columns—Reducing levels—Checking each page by totals—Field notes and remarks—Plotting sections—Reflecting levels—Contouring—Rough levelling with Aneroid Barometer.

FIELD LESSON 2.—Chain surveying on hilly ground—Use of Surveyor's card—Protractor and plumbob—Drainage level—Clinometer—Stepping with Chain—Chaining past obstructions—Setting out right angle with chain—Use of Abney's reflecting level—Use of Aneroid Barometer.

LECTURE 8.—Angular measurement—Vernier scale—Construction and adjustment of Box sextant—Transit theodolite—Everest theodolite—Mode of taking horizontal and vertical angles—Questions for home work.

FIELD LESSON 3.—Levelling—Time practice in setting up and adjusting Level—Reading Staff—Taking running levels with approximate section of route—Ordnance bench marks—Minus readings—Third decimal—Comparison of totals.

LECTURE 9.—Cases in which the theodolite is useful—Surveying by the compass bearings—By the back angle—By two stations—Enlarging a base line—Field notes for plotting.

FIELD LESSON 4.—Theodolite work—Setting up and adjusting Theodolite—Taking bearing—Reading horizontal and vertical angles—Setting up over a given station—Taking angle between two lines—Traversing with Theodolite.

LECTURE 10.—Copying plans by pricking through, and transfer—Enlarging and reducing by proportional squares—Use of Triangular and Proportional compasses—Use and adjustment of Eidograph and Pantagraph.

FIELD LESSON 5.—Compass survey—Use of Prismatic compass in a closed traverse—Adjusting Box sextant—Reading angles—Accessory station—Open traverse.

FIELD LESSON 6.—(60 Queen Victoria Street) Practical use and adjustment of Vernier protractor, Computing scale, Planimeter, Eidograph, and Pantagraph—Further inspection of instruments used throughout the course.

The Lectures will be given at the College on Thursday evenings 6 to 7 p.m., and the Field Lessons on Saturday afternoons 3 to 5 p.m. at various places in the vicinity of London.

FEE :—for the Ten Lectures and Six Field Lessons,

THREE GUINEAS,

or for the Six Field Lessons only,

TWO GUINEAS.

Enlarged diagrams of the various instruments will be exhibited in the Lectures, and a sufficient number of instruments will be provided in the Field for every student to obtain a fair share of practice.

Students attending this Course will be eligible for the Prize and Certificates awarded by the City of London College upon the results of the Annual Examination in June, candidates should hand in their names to the Librarian by the first week in May.

An additional Prize of £1 1s., given by the Professor, will be awarded to the student who submits the best Original Survey. Drawings to be handed in by the 1st July. For conditions see College Calendar.

GENERAL COURSE OF LECTURES AND FIELD-WORK

IN

Land Surveying and Levelling.

Part I.—CHAIN SURVEYING. (Ten Lectures).

LECTURE 1.—Introduction—Scope of lectures—Origin of the term Geometry—Distinction between theoretical, or pure geometry, and practical or applied geometry—Principles upon which Land Surveying is dependent—Difference between old system of surveying and modern systems—Objects in view in measuring land—Distinction between office and field work—Six selected problems in practical geometry—Linear measurement—British standard of length—Unit adopted varies in certain cases—Table of Linear measures—Square measure—Unit adopted in measuring land—Table of square measures.

Form of working in calculating areas—Pointing off—Rule for area of rectangular figure—Example—Rule for area of triangular figure when base and perpendicular are given—Example—Rule for area of triangular figure when sides only are given—Example—Rule for area of four-sided figure, having two sides parallel—Example—Irregular four-sided figure divided into two triangles by a diagonal—The same divided into two triangles and a trapezoid—Example—Method of tabulating the working—Drawing to scale or plotting—Description and use of chain scale—Decimal system.

Lecture 2.—Use of measuring tape—When desirable—Precautions to be observed—How angles are obtained—Practical example—Tie and Check Lines explained—All work must have tie lines, and the principal parts check lines in addition—Rule for distance of tie line from angle—How tape measurements are recorded—Gunter's chain—General description of its use—Field book, how used—Measurement of straight-sided fields and plots by base and perpendicular of component triangles—Use of station poles—How chain lines and stations are indicated in field book—Offsets—How measured and recorded—Various methods of obtaining perpendiculars—Practical illustration left for field course—Construction of optical square—Entries in field book—Bearing of base line—True north and magnetic meridian—Variation of compass—North point on plans—Examples of straight-sided fields from field notes.

Lecture 3.—Importance of offsets being correctly measured—No check upon them as upon chain lines—Secondary lines of survey should approximate to all boundaries and divisions—Length of offsets—Offset staff—Order of working in plotting from field notes—Use of offset scale—Character of outline for boundary—Area of offset piece—By tabulating area of space between each offset—By geometrical casting—Example—By equalizing line on tracing paper—Example—Equidistant offsets, when used—Ordinary rules for calculating area—Improved rule and formula—Example—Double offset piece—How calculated—Example.

Lecture 4.—How various boundaries are marked—Boundary stones, plates and marks—Building plots—Party walls, hedges and ditches—Why hedge is on inner side of ditch—Allowance for width of ditch—Fence boundary—Nails driven home—Marking owner's side on plans—Conventional signs—Office plans and finished plans—How each is prepared—Estate in detached portions, how plotted—Colouring and lettering plans—Colours for various objects and materials—Marking areas on plans—Surveying a three-sided field—Laying out chain lines by station poles—Check line—Order of measuring lines—Example.

LECTURE 5.—Chain lines outside any portion of field when better lead can be obtained—Caution in taking area by calculation when any inset pieces occur—Numbering the lines, usual plan in chain surveying instead of lettering stations—Irregular four-sided field—Example Station not necessarily at commencement of line—Chain lines—Tie and Check lines—A, K, and X systems of lines—Hedge crossing chain line, how shown in field book—Post and rail fence—Open pale fence and close boarded fence, how shown on plans—Hedge, how shown—Colour of hedge.

(Field Work commences here.)

LECTURE 6.—Selecting and marking stations—Sighting through or ranging the poles—Station not necessarily at extremity of chain line—Sheds and unimportant buildings taken by offsets and sketch in side column—Chain line crossing road and footpath—Auxiliary stations marked by whites—Irregular five-sided field—Example—Importance of neat draughtsmanship—Traversing with chain—Methods of tying angles.

LECTURE 7.—Typical outlines of chain surveys—Check lines essential unless chain lines mutually check each other—Continuation of chain line often available as a check—System of lines when the area alone is required of the part surveyed—Field notes of chain lines (without offsets) from several surveys.

LECTURE 8.—Surveying woods, lakes, marshes, standing crops, &c.—Chaining outside boundary involves more difficulty than inside, because of hedges, fences, ditches, &c., to cross—Typical chain lines for surveys outside boundary—Example of survey of a lake—Plotting and colouring—Examples of a survey of a wood—Representation of trees of various kinds—Clumps of underwood.

LECTURE 9.—Obstruction to continuation of chain line—Setting up perpendicular with chain—Property of triangle having its sides in the proportion of 3, 4, and 5—Setting up angle of 60° with the chain method of working when obstruction does not impede the view, as a lake, stream, &c.—Another method—Additional precaution when the view is obstructed—To measure the distance of an inaccessible point, width of river, &c.—To continue chain line across river—Method with cross staff—Examples.

LECTURE 10.—Plans and maps—Various systems of projection—Curvature of the earth not taken into account in ordinary surveys—Ordnance survey maps—Surveying over hilly ground—Correction for inclination—Why necessary—Table of reduction in links for various angles of inclination—Mode of indicating hilly ground on plans—Direction of hachures—Contour lines—Notes from instructions to surveyors for the preparation of plans for the Tithe Commission—Field notes of survey of small estate, to be plotted.

Part II.—CHAIN SURVEYING. (Six Field Lessons).

Commencing after Lecture 5, Part 1.

Field Lesson 1.—Throwing chain—Setting station poles—Ranging line—Taking bearing of base line—Use of cross staff—Use of optical square—Measuring portions of field staked out in straight-sided plots—By base and perpendicular—By boundaries and tie lines—Marking secondary stations by whites.

Field Lesson 2.—Laying offset staff perpendicular to chain—Measuring offsets—Long offsets hand over hand—Recording surrounding objects in offset column of field book—Connecting adjacent offset pieces—Traversing with the chain.

Field Lesson 3.—Survey of lake—Setting out stations—Tie and check lines—Insets to margin—Position and size of Island obtained by tangents from stations—Junction line to second pond.

Field Lesson 4.—Survey of open land intersected by footpaths—Parish boundary—Offsets taken by tape.

Field Lesson 5.—Setting up right angle with the chain—Chaining past obstructions—Detours, various modes.

Field Lesson 6.—Surveying on hilly ground—Judging rise or fall—Taking same by protractor and plumbob—Ditto by surveyor's card—Ditto by drainage level—Ditto by clinometer compass—Stepping with chain—Survey of portion of hill including boundaries and footpaths.

Part III.—LEVELLING. (Two Lectures and Four Field Lessons).

Lecture 1.—Introduction—Definition of levelling—Datum line—Distinction between level and horizontal—Definition of a level surface—Description of Gravatt's Dumpy Level—Adjustments and mode of using—Description of sliding staff—Effect of curvature of earth—Correction for this—Correction for refraction—Apparent height and actual height—Formula for reduction of any given observation—When corrections are necessary, and how avoided—Error from omission not appreciable in ordinary sights—Simple and compound levelling.

Lecture 2.—Ordnance survey maps—Ordnance datum—Trinity datum—Levels—Bench marks—Flying or running levels—Check levels—Final levels—Main section — Cross sections—Field notes in level book—Back, intermediate, and fore sights—Rise or fall—Reduced level—Height above base—Checking by totals—Allowable error—Distances—Correction for inclination, when required — Plotting sections.

Field Lesson 1.—Time practice in setting up and adjusting level—Reading staff on short and long sights—Ordnance Bench marks—Practice in taking flying levels and returning to same point.

Field Lesson 2.—Taking running levels with approximate section of route—Distances obtained by pacing—Minus readings—Third decimal, how dealt with—Comparison of totals, each student entering his own reading.

Field Lesson 3.—Main and cross sections—Working levels.

Field Lesson 4.—Staking out building plots on irregular ground with cross staff—Taking levels from a single station—Shifting the station—Incidental work.

The field work is taken on Saturday afternoons at various places in the vicinity of London, according to the nature of the work. The following places have been visited by the students: Clapham Common, Hampstead Heath, Primrose Hill, Muswell Hill, Hackney Marshes, Epping Forest, &c. When the number of the students renders it desirable additional instruments are provided, so that all may have a fair share of practice.

Fee:—ONE GUINEA.

For each part of the course, including use of instruments and assistant, but exclusive of railway fares. If prepayment be made in one sum for the three Parts the fee will be £3, or for the field lessons alone £2 2s. Each student will require a Field Book (1s. 6d.); Level Book (2s. 6d.); Universal Chain Scale and Offset (6s.), all of which can be obtained in the class.

The periods of meeting are approximately as follows:—Part I., October to December; Part II., November to December; Part III., December; but unless a student joins at the commencement he should make enquiry as to the later dates.

A Prize of £1 1s. will be given by the Council of the College to the student who, having regularly attended the Lectures and Field Work of the current session, passes the best Examination. Certificates of three grades will also be awarded.

An additional Prize of £1 1s., given by the Professor, will be awarded to the student who, of three competitors, submits the best Original Survey of not less than 10 acres in extent, with a section through it at least 10 chains long, and field notes. Drawings to be handed in by the 1st July.

INTERVAL FOR SPECIAL COURSE.

NOTE.—Students desiring to attend any of the following Supplementary Courses should send in their names by the 1st March at the latest, in order that the necessary arrangements may be made. The fees for these are paid direct to the Professor.

Theodolite Work.

Part I.—THEODOLITE WORK, ELEMENTARY. (Three Lectures and Three Field Lessons).

LECTURE 1.—Introduction—Principle of Theodolite—Distinction between Theodolite surveying and chain surveying—Angular measurement—Notes on angles—Unit of measurement—Sub-divisions—Protractors: circular, semi-circular, and rectangular—Construction of protractors—Scale of chords—Construction of scale of chords—To set off, or measure an angle, with a protractor or scale of chords—Terms used in connection with angles and triangles—Various useful properties of angles—Principle of Box sextant—Diagram of construction.

LECTURE 2.—Vernier scale—Enlarged working model—Explanation—Construction of theodolite—Setting up and adjusting—Taking magnetic bearing—Reverse bearing—Taking horizontal angles—Repeating the angle—Taking vertical angles—Surveying by the compass bearings—By the back angle—By two stations—Field notes of survey from two stations, including chain lines and offsets.

LECTURE 3.—Cases in which theodolite is required—Surveying by back angle—Example of survey of lake—Check upon angles of a closed traverse—Example of survey of road through forest—Check observation to a previous station—Example of survey of river—Calculation of areas.

FIELD LESSON 1.—Practical work in setting up and adjusting Theodolite—Setting up over given station—Taking bearing of base line—Reading angles.

FIELD LESSON 2.—Practice in surveying by back angle—Traversing with Theodolite.

FIELD LESSON 3.—Survey of field from two stations—Assistance of Theodolite in chain surveys.

Part II.—THEODOLITE WORK. TRIGONOMETRICAL. (Four Lectures and Two Field Lessons.)

NOTE.—*In this Course it is assumed that students have no previous knowledge of mathematics.*

LECTURE 1.—Determination and comparison of angular magnitudes—Meaning of term ratio—Definition of the sine of an angle—Trigonometrical functions and ratios—Assistance derived from mnemonics—Complement and supplement of an angle—Angles in the second quadrant—Examples.

LECTURE 2.—Construction of logarithms—Base, index and mantissa—Use of logarithmic tables—Multiplication, division, involution, evolution by logarithms—Table of natural sines and cosines—Table of tangents, &c.—Examples.

LECTURE 3.—Formulæ for heights and distances— On level and sloping ground —Accessible and inaccessible objects—Sketches shewing application—Examples.

FIELD LESSON 1.—Setting out base line on level ground—Observations to various distant church spires—Calculation of distances—Enlarging base —General triangulation work.

FIELD LESSON 2.—Setting out base line on sloping ground—Taking levels with Theodolite—Observations for height to top of Structure—Checking by second set of observations—Work to be plotted and calculated.

LECTURE 4—Practical work in trigonometrical calculation—Use of formulæ and tables.

Fee—One Guinea each part.

Engineering Field Work.

(Four Lectures and Two Field Lessons.)

LECTURE 1.—General route—Setting out on the straight—Ranging both ways —Instruments used—Permanent Stakes—Level pegs—Bench marks—Staking at embankments and cuttings—Bridge sites—Gradients—Batters and slopes—Formation breadths—Setting out side widths—Diagrams and formulæ—Working section book.

LECTURE 2.—Curves—Modes of designating radius—Angle of deflection—Nomenclature of curves—Computation of curves—Boundaries given, to find radius—Radius given to find boundaries—Curve formulæ and tables.

LECTURE 3.—Various systems of setting out curves—Ranging curves—Common method—By oblique offsets—By rectangular offsets—By angles of deflection with one theodolite.

LECTURE 4.—Setting out curves continued—By angles of deflection with two theodolites—By Baker's parabolic system—By the single chord system —Curves on bridges and viaducts—Compound curves—Crossings turnouts—Super-elevation of outer rail.

FIELD LESSON 1.—Setting out on the straight—Staking out side widths on irregular ground.

FIELD LESSON 2.—Ranging curves with chain and theodolite on various systems.

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Town Surveying.

(Two Lectures and one Field Lesson).

LECTURE I.—Distinction between Town Surveying and ordinary Land Surveying—Theodolite essential—Connection with surrounding triangulation—Base and tie lines—When angles may be omitted—Stations how marked—Chains and Tapes—Rectangular offsets—Oblique or triangulated offsets—Method of keeping field-book for chain lines—Field book for details—Order in plotting work—Hints on sketching and putting in measurements—Examples of lines and angles of Town Survey from field-book without the offsets—Example of one line with offsets and sketches.

LECTURE II.—Difference in laying out between ancient and modern towns—Causes of same—Ordnance town maps of various scales—Limit of accuracy determined by the scale adopted—Table of limits—Double chain lines—Example of same with sketches from field-book—Detail of back premises, how measured—Precautions to be adopted—Examples from field-book.

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